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VOLUME I

PICTORIAL FORMATS

Volume I Format Development



R. A. JAUER
T. J. QUINN
McDONNELL AIRCRAFT COMPANY
McDONNELL DOUGLAS CORPORATION
P.O. BOX 516
ST. LOUIS, MISSOURI 63166

February 1982

Final Report for Period May 1980 - May 1981

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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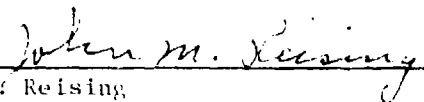
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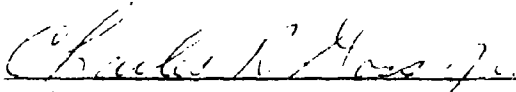
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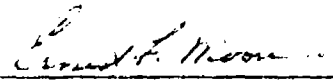
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This technical report has been reviewed and is approved for publication.


J. Reising
Engineering Psychologist
Crew Systems Development Branch
Flight Control Division


CHARLES R. GOSS, JR., Lt Col, USAF
Chief
Crew Systems Development Branch
Flight Control Division

FOR THE COMMANDER


ERNEST F. MOORE
Colonel, USAF
Chief, Flight Control Division

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-81-3156	2. GOVT ACCESSION NO. AD-A119 222	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PICTORIAL FORMATS Volume I. Format Development		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report May 1980 - May 1981
7. AUTHOR(s) R. A. Jauer T. J. Quinn		6. PERFORMING ORG. REPORT NUMBER MDC A7172 Vol. I
9. PERFORMING ORGANIZATION NAME AND ADDRESS McDonnell Aircraft Co. McDonnell Douglas Corporation P.O. Box 516, St. Louis, Missouri 63166		8. CONTRACT OR GRANT NUMBER(s) F33615-80-C-3601
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Wright Aeronautical Laboratory (AFWAL/FIGR) Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS P.E. 62201F Project 2403 04 20
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE February 1982
		13. NUMBER OF PAGES 129
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Cockpits Electronic Display Systems Stores Management Display Formats Crew Systems Primary Flight Display Formats Engine Display Formats Multi-Mode Display Formats Human Factors Engineering Tactical Situation Display Formats Emergency Procedures Display Formats		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Pictorial Format Study (Volume I) includes the development of displays for six primary fighter crew station functions (e.g., primary flight, tactical situation, stores management, systems status, engine status, and emergency procedures). The study focused on information that the pilot really needs. Possible changes in cockpit data requirements reflecting future aircraft systems and performance were examined. Pictorial Formats were generated in monochrome stroke, color stroke and color		

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raster. The color raster formats are the most aesthetically pleasing. The study indicates that pictorial formats should include limited use of alpha-numeric characters to add the precision that certain situations/systems require. The use of color was found to enhance information transfer in situations where the pilot must distinguish between classes of stimuli

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PREFACE

This report covers work performed for the Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory (AFWL/FIGR) under Contract No. F33615-80-C-3601. Dr. John Reising served as the project manager. The work was performed by the Advanced Crew Station Project Group, Advanced Engineering Division of McDonnell Aircraft Company, St. Louis, Missouri.

The authors would like to thank Dr. John Reising and Capt. C. J. Kopala of AFWAL/FIGR, Dr. Lloyd Hitchcock of NADC, and Lt. Andy Kraska of AFATL/DLJA for their guidance and contributions in developing these formats.

In addition to the authors, significant contributions were made by Vincent Fleming, Paul Summers, and Gerry Jensen. The invaluable assistance in preparing this report is acknowledged of: Tom Blethroad, Jim Surber, Mike Hennesy, George Bauer, Carol Cotner, and Carol Auchly.

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1. INTRODUCTION

The objective of this study was to develop pictorial display formats that make it easier and quicker for pilots of advanced aircraft to assimilate data needed for effective weapon system performance. The study imposed one major constraint on format development: emphasis was to be placed on using only pictorials in formats, with minimal use, if any, of alphanumerics. Traditionally, crew station information has been, and currently is, presented alphanumerically. In this study we were tasked with exploring and working with the other extreme of information presentation - pictorials. We have developed formats for displaying primary flight data, the tactical situation, stores management data, systems status and emergency situations with corrective action. The systems covered are the engines, fuel, hydraulic and electrical. An estimate of the computational power needed to generate these formats is included in Volume II. The recommended formats reflect a combination of innovative inspirations based in part on the conceptual formats shown in Volume III of this report.

The concept of using pictorials as part of an aircraft instrumentation package is not new. As revealed in the literature search, many pictorial concepts, particularly the primary flight displays, are decades old. Greater memory capacities and faster computer throughputs, combined with decreasing weight, volume, and cost have recently opened the way to practical and economical implementation of these concepts.

The idea for this study was germinated by the pictorial formats used for the stores management display on the F/A-18 aircraft. Figure 1 (a) shows how weapon status displays have evolved through alphanumerics to graphic pictorial formats. Two questions frequently asked by pilots are illustrated in Figure 1 (b). These exemplify the basic differences and complementary characteristics of alphanumeric and pictorial formats. The alphanumeric format -- Answer B -- can be the better answer, and until recently it might have been the only available answer. This study is directed at the pictorial format -- Answer A -- and how it can best be used.

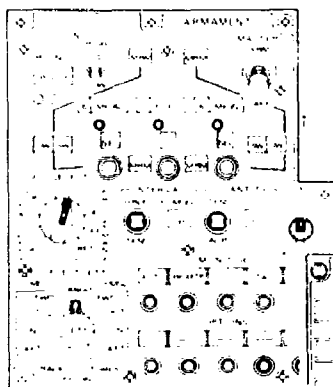
The pictorial formats presented in the study results should be viewed as illustrations of ways to break the old aircraft instrumentation molds. While creativity was allowed and encouraged to flow without constraint, there were - and always will be - some constraints. These were inevitably encountered when selecting what to display. The following are several examples.

The primary flight display can be designed with a flight channel. It can be a color raster image of the outside world. Or, it can be simply a velocity vector and a flight director. The choice is constrained by what parameters are available from aircraft systems such as flight control and navigation, the pilot relief mode (or flight control mode) being used, visibility of the outside world, and the pilot's preference, even though no constraints are assumed for the image generating and display system.

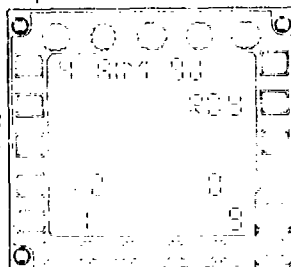
The flight displays are applicable to many aircraft. Air speed, altitude, and attitude are monitored by pilots in all aircraft. The system status displays do not have this same degree of generic application. The electrical system status assumes a dual generator system with battery backups. A different set of displays would be developed for a single generator system, or one with a spare generator backup.

a) EVOLUTIONARY PROGRESSION

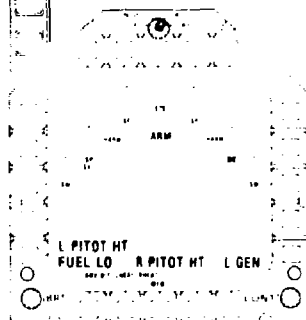
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b) CONVENTIONAL PICTORIAL FORMATS

WHAT'S MY ALTITUDE?

ANSWER A

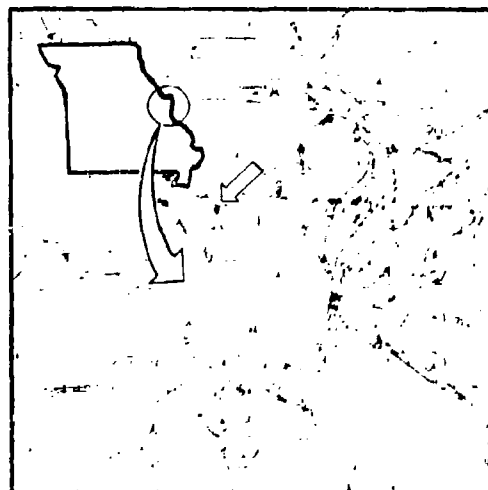


ANSWER B

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1550 FT RDR

WHERE AM I?

ANSWER A



ANSWER B

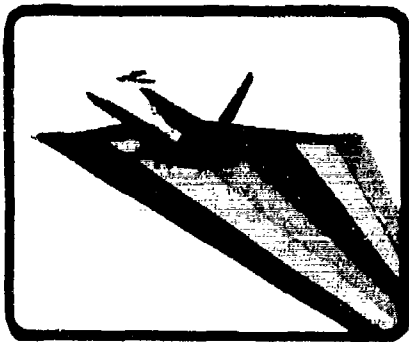
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38°45'30" NORTH

Figure 1
Philosophy of Pictorial Formats

The engine displays exemplify one of the most influential factors in developing aircraft instrumentation displays -- pilot preference. Reliability and accuracy play a key role in shaping pilot preference. The formats shown in this study reflect pilot preference for having engine speed and temperature data. An evaluation of required data shows that this raw data could be replaced with a simple indication of "go," "caution," or "no go" for an engine, analogous to indicator lights used in automobiles. As display, computer, and avionic system reliabilities prove themselves, pilot preference may change to even simpler engine status formats.

All the reported formats were selected from several preliminary versions. In many cases the selection margin was very narrow.

2. PRIMARY FLIGHT DISPLAYS



When developing this section of displays several things had to be considered, even though the program had "no constraints" other than focussing only on pictorials. Displays are limited to a reasonable field of view. The pilot needs visual access to the real world, thus he needs both head-up display (HUD) and head-down displays. The pilot's tasks, which include manual flight control and automatic flight control with advanced concepts such as integrated flight weapon control (IFWC) or integrated fire/flight

control (IFFC), were of primary importance in defining display and control requirements. Sensor management functions are needed for target acquisition and attack. Threat avoidance and threat evasion, as well as flight paths compatible with advanced flight control/navigation systems generate additional critical display requirements.

The required information parameters included those needed on prior aircraft projects such as the F-4, F-15 and F/A-18. The parameters that have to be displayed to the pilot include ground speed, air speed, mach, radar altitude, barometric altitude, angle of attack, pitch and roll attitude, glide slope location, heading, bank and pitch steering, slip or crab, vertical velocity and elapsed time. Typically these parameters are provided through the following instruments: an attitude director indicator (ADI), a horizontal situation indicator (HSI), barometric and radar altimeters, an airspeed/mach indicator, a true airspeed indicator, an angle of attack indicator, a vertical velocity indicator and a clock.

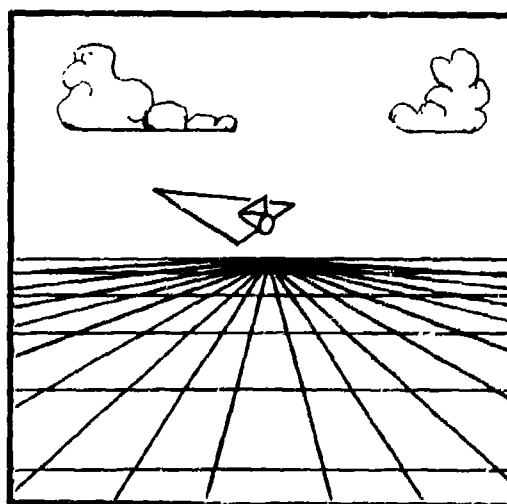
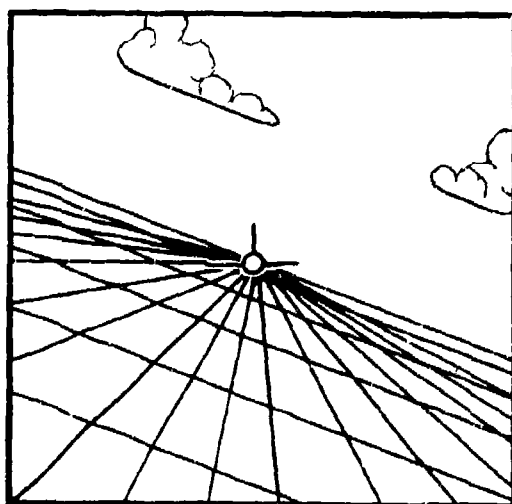
The F-15 and later aircraft projects integrate much of this information into a graphic format on the HUD. The graphic data displayed in the HUD format include items such as indicated air speed, steering data, and a myriad of weapon control features (for both air-to-air and air-to-surface attack). The HUD format also includes many alphanumeric entries such as instrument landing system (ILS) markers, g load, and radar range. The conventional HUD formats that are available today meet most of the needs of flight displays. In fact, they serve quite well and are one of the options available as a pictorial format.

Both HUD and head-down displays are necessary. Each requires a 1:1 scale with the real world. The head-down display is characterized by a real image, and it can be used to transition to a tactical situation display in which the scale then changes from 1:1 to a much smaller scale providing an outside-in view. The generic head-up display is a helmet mounted display (HMD), has a nearly spherical field of regard, a virtual, collimated image, with a 1:1 scale that registers the format with the real world, and provides an inside-out view. The head-down display has no

direct real world superposition on the image, but the head-up display, because it does look out into the real world, has real world information superposed on the display (if the weather conditions are appropriate). These last two points are significant considering the complexity of the display. Excessively complex displays will interfere with the outside world scene and cause problems for the pilot when he attempts to interpret the display. If the outside world is obscured by weather or night, there is essentially no outside world visible and the head-up display functions the same as a head-down display. The outside scene, then, is a factor in the pilot's decision to select a head-down instead of a head-up format or the type of display that he wants to use when he goes to head-up. In this report the expressions "HUD" and "head-up" mean a generic capability. It is assumed, that formats shown for head-up viewing can be used on either a conventional HUD or an HMD.

One of the basic decisions was whether we wanted to use an inside-out or an outside-in format. The two concepts are illustrated in Figure 2. The inside-out concept is the one conventionally used by most ADI displays common to aircraft instrument flight over many decades. The outside-in concept has had many attempts at being used but none have really been operationally successful. The biggest advantage of the outside-in is that the world can be scaled and the display used to give the pilot a birds-eye view of the situation. This type display is applicable to the tactical situation display and is discussed in Section 3.

VIEW POINT



INSIDE - LOOKING OUT

OUTSIDE - LOOKING IN

**Figure 2
View Point**

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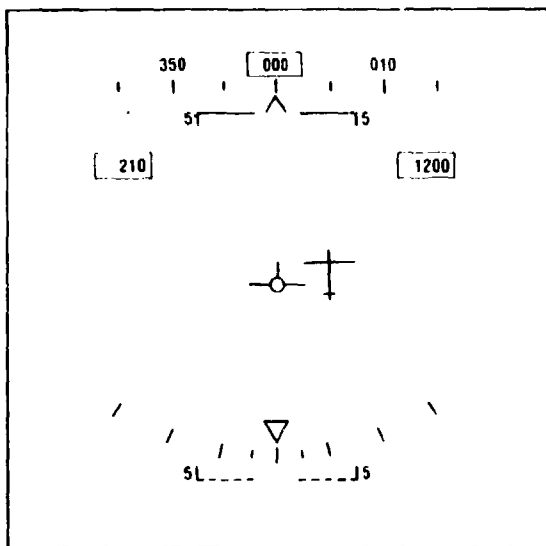
2.1 TYPES OF FLIGHT DISPLAY

Figure 3 shows the four basic types of flight displays that are applicable to the pilot's needs. Figure 3a) is a conventional HUD format. It represents the many format variations that are used for the primary flight modes such as navigation, air-to-air or air-to-surface. The flight channel, Figure 3b), is an improvement over the conventional HUD because it gives the pilot a path in the sky which may prove easier to follow than is the flight director on the HUD. Generating a flight channel requires more computational effort, however, than generating a flight director on the HUD. It has not been used in any operational aircraft today. The graphic terrain and pictorial terrain formats in Figures 3(c) and 3(d) extend the flight display to allow instrument flight rules (IFR) operation similar to visual flight rules (VFR). These displays give the pilot a much more realistic feeling for the terrain, his attitude, speed and the other parameters normally associated with flight, but at the expense of considerably more data processing and storage requirements. In fact they give him an instant impression, or interpretation, of altitude, roll, pitch, ground speed, angle of attack, heading, vertical velocity, crab angle, and accelerations. Even this may not be enough, however. Often, the pilot must maintain a commanded velocity direction, especially when flying instruments on takeoff, landing approaches, terrain following (TF), or terrain avoidance (TA) mission phases. For these situations the pictorial or graphic features can be supplemented with the flight channel or the conventional HUD flight director in combinations as shown in Figure 4.

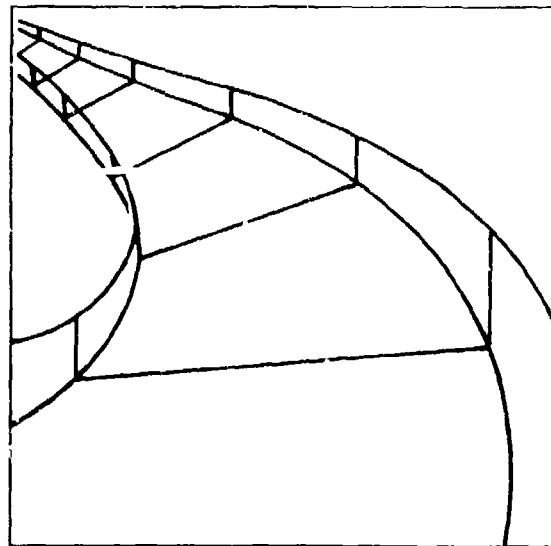
The decision when and what type of augmentation to use for any display is a function of the flight mode. The five basic types of flight modes are illustrated in Figure 5. The sky track is a fixed-in-space path comparable to an established path for takeoff and landing or a flight plan which has been made prior to the mission. During a mission the pilot might want to select a different mode. Free flight assumes no steering guidance. Projected flight path is based on the aircraft's current location, velocity and accelerations. Assuming those parameters remain constant, a path is projected in front of the aircraft. They do not stay constant, however, and the flight path would continually move and wiggle on the display. This type of path can be used by the pilot to help him evaluate when to change course to avoid objects in TF/TA modes.

In addition to the projected flight path, there are commanded modes in TF/TA operations in which precise paths would be projected. Automatic TF or TA modes of operation would provide paths which the aircraft automatically follows. The pilot simply "goes along for the ride" and monitors the display to determine that the system is operating properly.

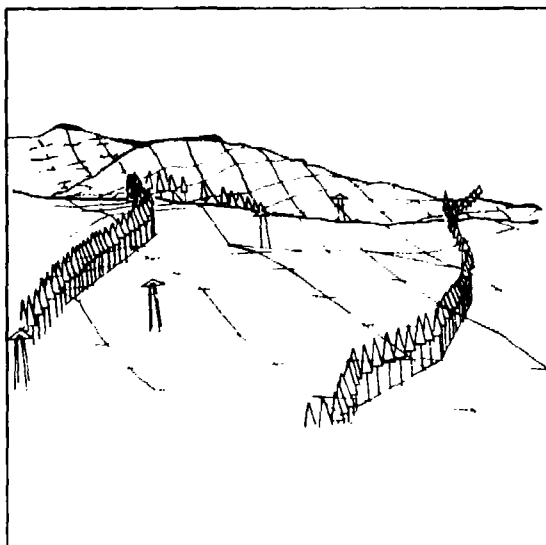
The command path is used to transition the aircraft from some known location to a sky-track or other predetermined location. It requires that current aircraft location is known, specifically where it should be at a future time, and the attitude at those future locations. A later discussion will detail which flight displays apply to which flight modes.



a) CONVENTIONAL HUD



b) FLIGHT CHANNEL



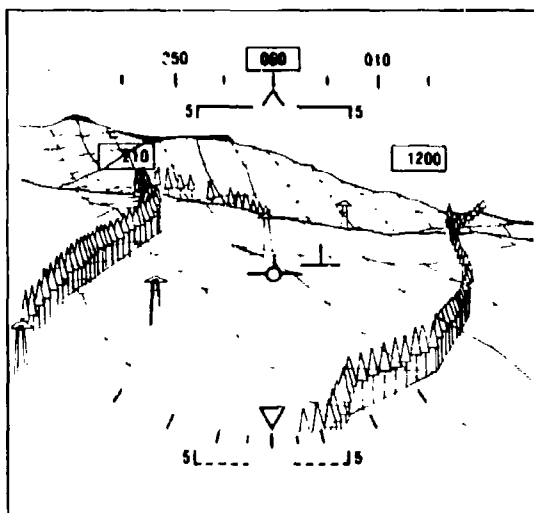
c) GRAPHIC TERRAIN



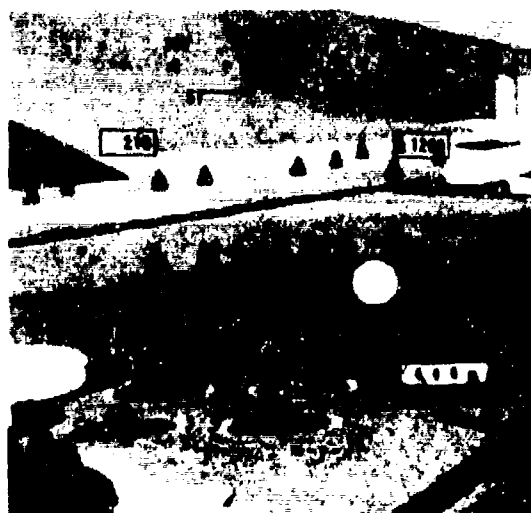
d) PICTORIAL TERRAIN

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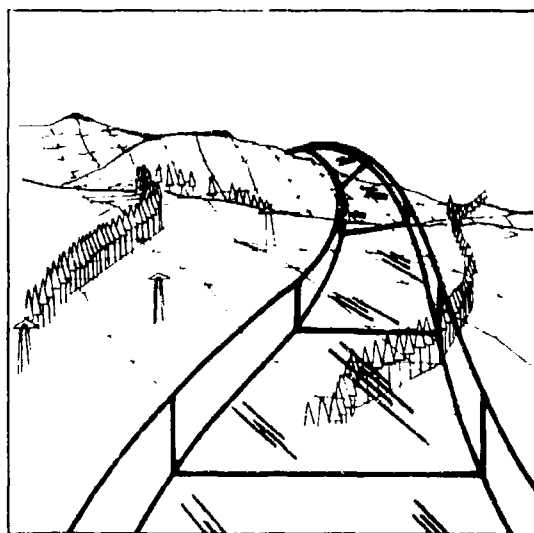
Figure 3
Primary Flight Display Formats



a) HUD/
GRAPHIC TERRAIN



b) HUD/
PICTORIAL TERRAIN



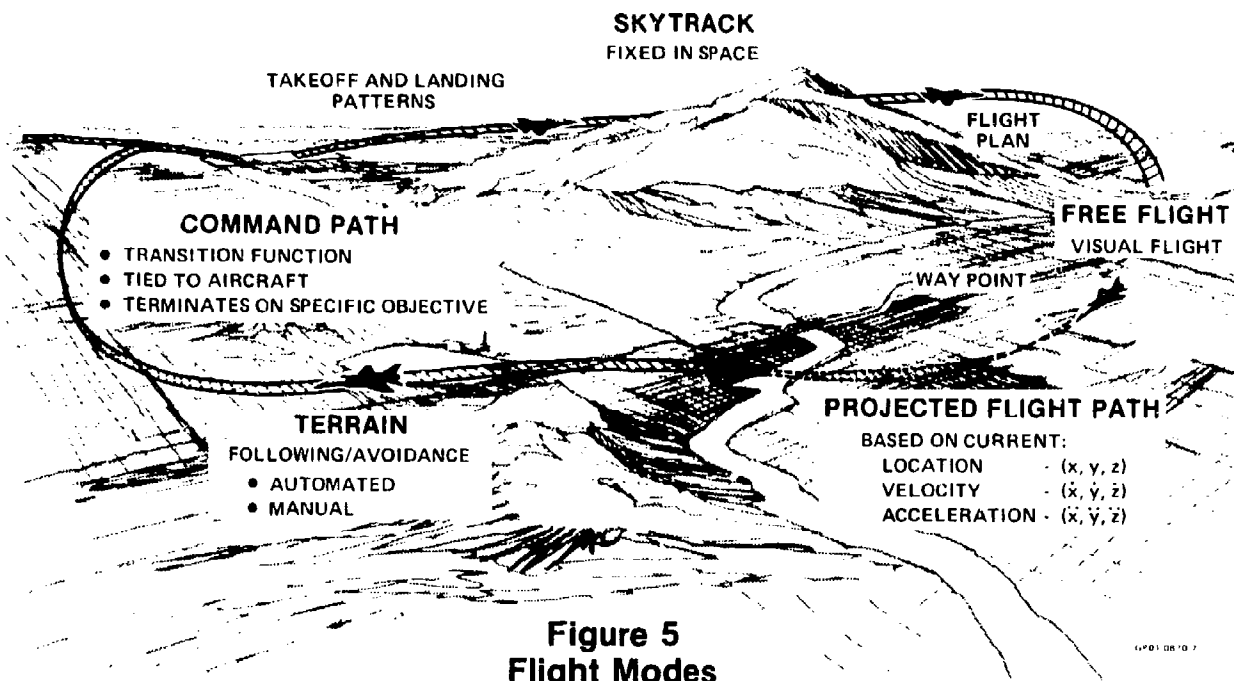
c) CHANNEL/
GRAPHIC TERRAIN



d) CHANNEL/
PICTORIAL TERRAIN

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Figure 4
Combination Formats for Flight Displays



2.2 APPLICATIONS

Aircraft altitude is a major factor in what type of flight display is used. At higher altitudes, less terrain detail is required to give the pilot sufficient altitude, attitude and velocity cues. At lower altitudes more detail and more precise information are required as shown by the graphic and pictorial formats in Figures 3 (c) and 3 (d).

For flight at mid-altitude and higher, a relatively simple format consisting of an earth stabilized grid and air movement as indicated by clouds which translate through the scene is sufficient. This format is illustrated in Figure 6, for a generic head-up, or helmet mounted, display. The aircraft is flying due north. Looking forward, as in the center image of the figure, the pilot would see the two clouds grow from small points and go off the upper corners of the display. The grid would translate underneath the aircraft as it flew over the earth.

Other images in Figure 6 depict scenes the pilot could see by looking in different directions. If he looked up he would see the clouds move from the bottom part of the display to the top which is towards the rear of the aircraft. This assumes that the aircraft continues flying due north. Views are shown of what the pilot would see as he rotated his view first to 45° right and then to 90° right. Indications of how the clouds and grid would translate through each scene are also provided. Similar scenes are shown for a rotation to the left, although the clouds and grid would translate in the opposite direction.

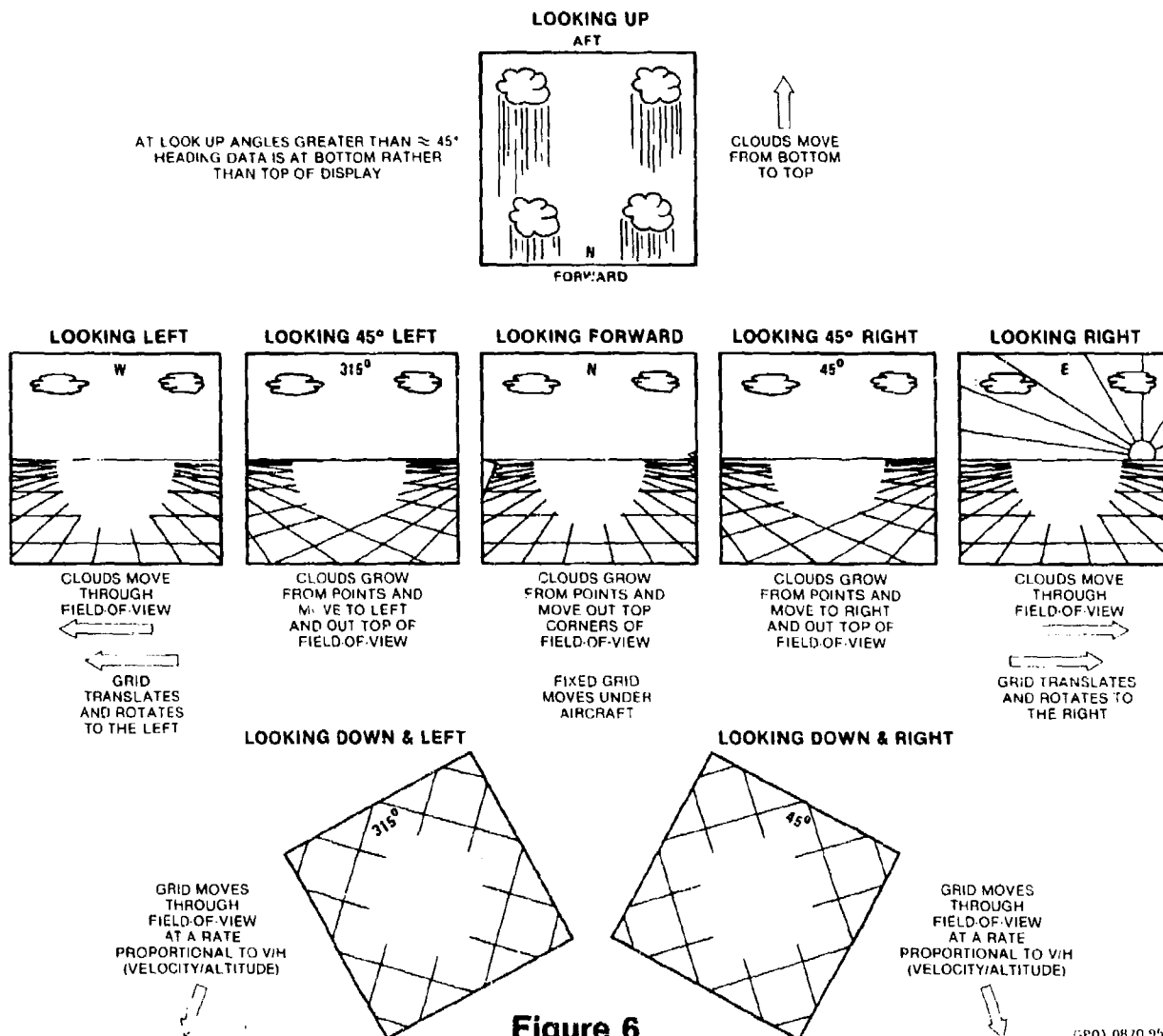


Figure 6
Head Up Pictorial — Inside Looking Out

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Since the display is not limited by the aircraft, he could look down through an "invisible" aircraft.

This modest grid format would give a peripheral indication of the parameters previously sighted, i.e., altitude, roll, pitch, etc. By translating the clouds through the scene the format gives an indication of air speed and angle of attack. If the aircraft is at an appropriately low altitude an impression of angle of attack can be obtained from the grid alone. Simplistic as it is, when dynamic, it would give a good impression of these flight parameters.

Precise numbers are often needed for flying a specific course, landing glide path, takeoff, or certain cruise operations. Different ways of achieving that are illustrated in Figure 7. The basic display is shown in the figure center with the grid and clouds format. The format options in the periphery of the figure (HUD and flight path combinations) can be inserted in the center to complete the display as needed, or desired, by the pilot. This corresponds well with the pilot's visual characteristics. The peripheral information does not require great static accuracy in presentation, and matches the pilot's quasi-peripheral vision requirements because it is a mere impression of the parameters altitude, airspeed, ground speed, etc. However, the precise information obtained from the alphanumeric, or from the movement of the flight directors or flight channels, is within the pilot's foveal vision cone. Selecting the insert is a function of the pilot's choice, phase of the mission, or limits of the control/navigation system that is supplying the basic flight command information. These factors also impact the display selections made for lower altitude operation.

MID-HIGH ALTITUDE

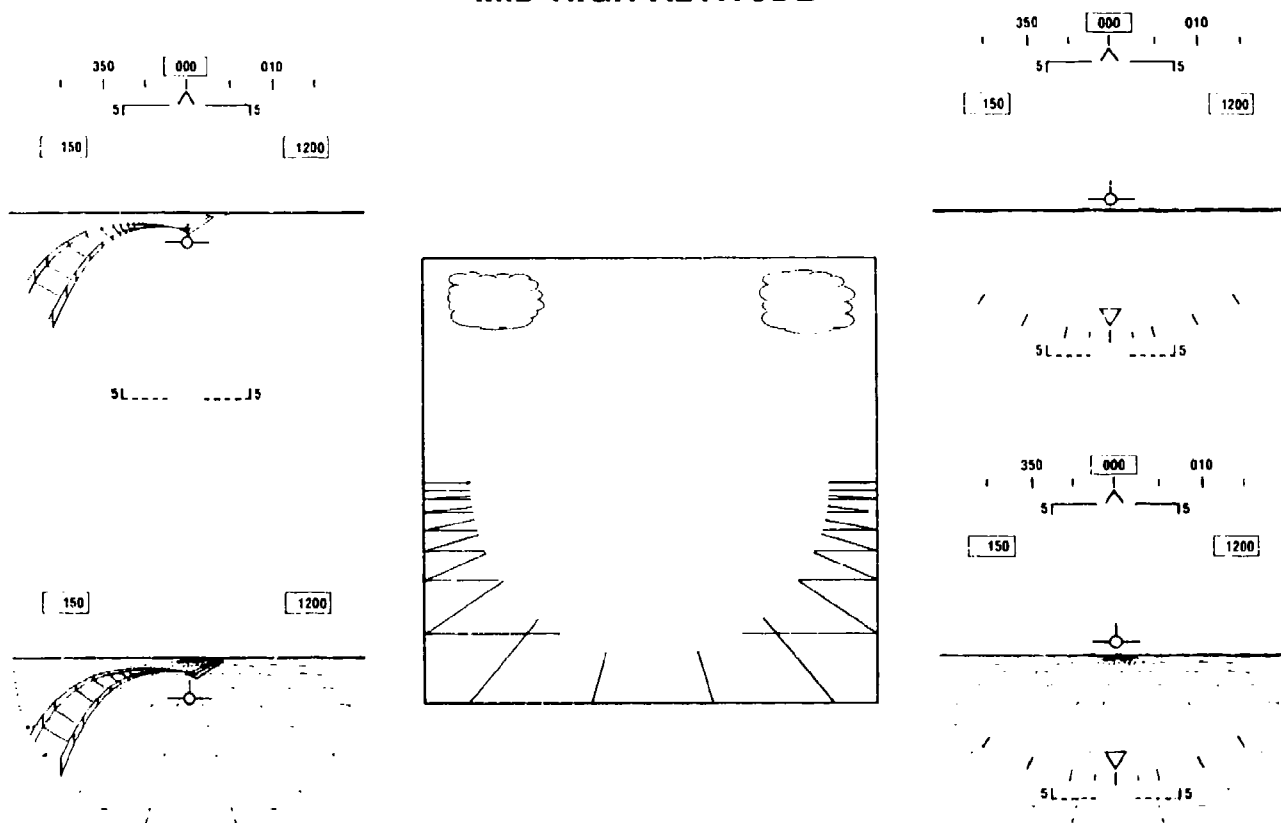


Figure 7
Head Up Format Options

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For low altitude operations, elevation data is included as the third dimension in the stabilized grid to provide the graphic terrain format in Figure 3(c). If more realism is needed the pictorial terrain format, Figure 3(d), is used. Other selection criteria remain the same. When there are no visibility restrictions and a head-up display is used, the format options illustrated in Figure 8 are applicable. If the real world view is blocked due to inclement weather or night operations, or a head-down display is used, there is no visual competition with the outside world. The format options applicable to each flight control mode with these conditions are illustrated in Figure 9. They include the full raster color displays, the line graphic displays and combinations with flight channels or HUD flight director information. In free flight the line graphic and the raster displays permit the pilot to operate as though it were VFR conditions. The other command modes all require formats that are supplemented with flight channel or HUD flight director information. It is not necessary that the pilot use the line graphic or raster display modes for inclement weather, night or head-down operation except for free flight mode. He can continue to use the simpler displays as illustrated in Figure 8.

PRIMARY FLIGHT DISPLAYS LOW ALTITUDE SUMMARY CLEAR DAY AND HEAD UP FORMATS

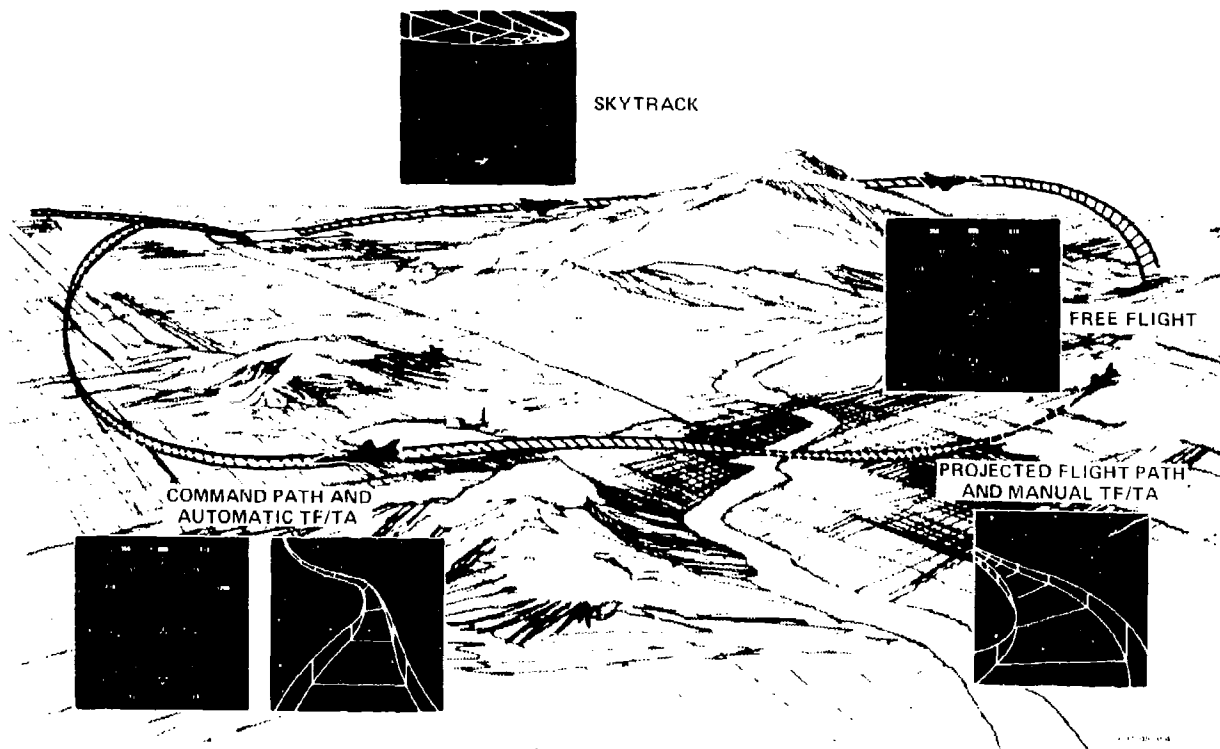


Figure 8
Low Altitude Summary
Clear Day and Head Up Formats

PRIMARY FLIGHT DISPLAYS **LOW ALTITUDE SUMMARY** INCLEMENT WEATHER, NIGHT TIME, OR HEAD DOWN DISPLAY

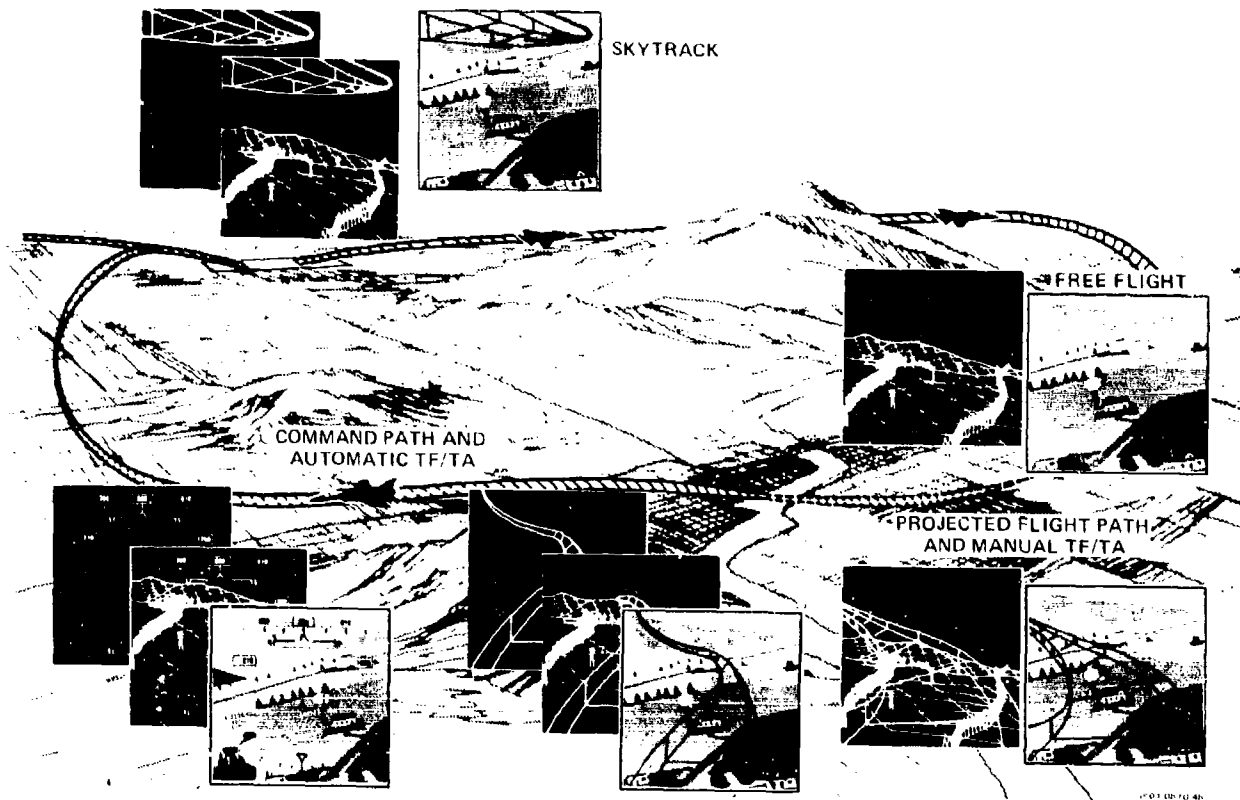


Figure 9
Low Altitude Summary

Color versions of these formats were also developed. The color stroke displays are illustrated in Figure 10. When operating at lower altitudes the grid's altitude dimension becomes prominent and the format is a color stroke version of the graphic terrain format in Figures 3 and 4. The color coding remains the same. Colors have been selected to contrast with each other, with background in the scene, and to retain identities throughout the other displays when possible. For example the white velocity vector and white information depicting altitude, air speed, heading, and bank angle all rely on having white as "self" designation. The aircraft symbol and other features denoting self are white when practical. Likewise orange is used for scales when possible. In this example, yellow and orange are both used to separate the pitch ladder and heading and bank, or roll, scales.

The color raster formats are filled versions of the color stroke format, as illustrated in Figure 11. The same conventions in coloring apply to the color raster displays. At lower altitudes a more realistic color raster display would be available at the pilots option, as shown in Figure 12.

MID-HIGH ALTITUDE

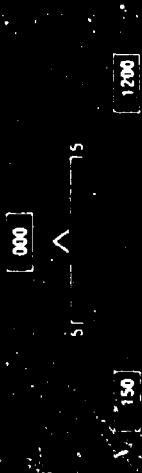
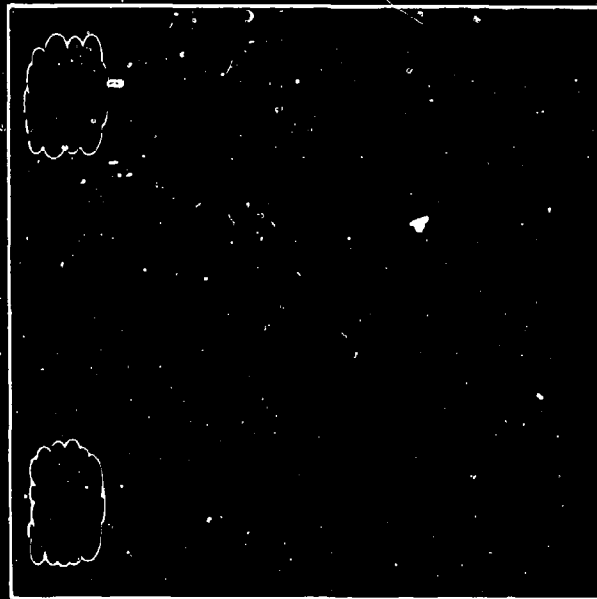
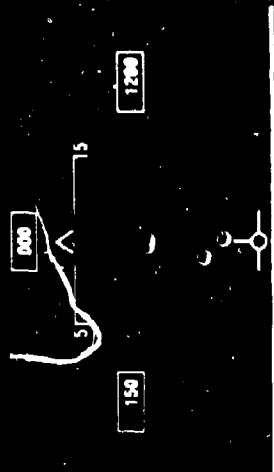
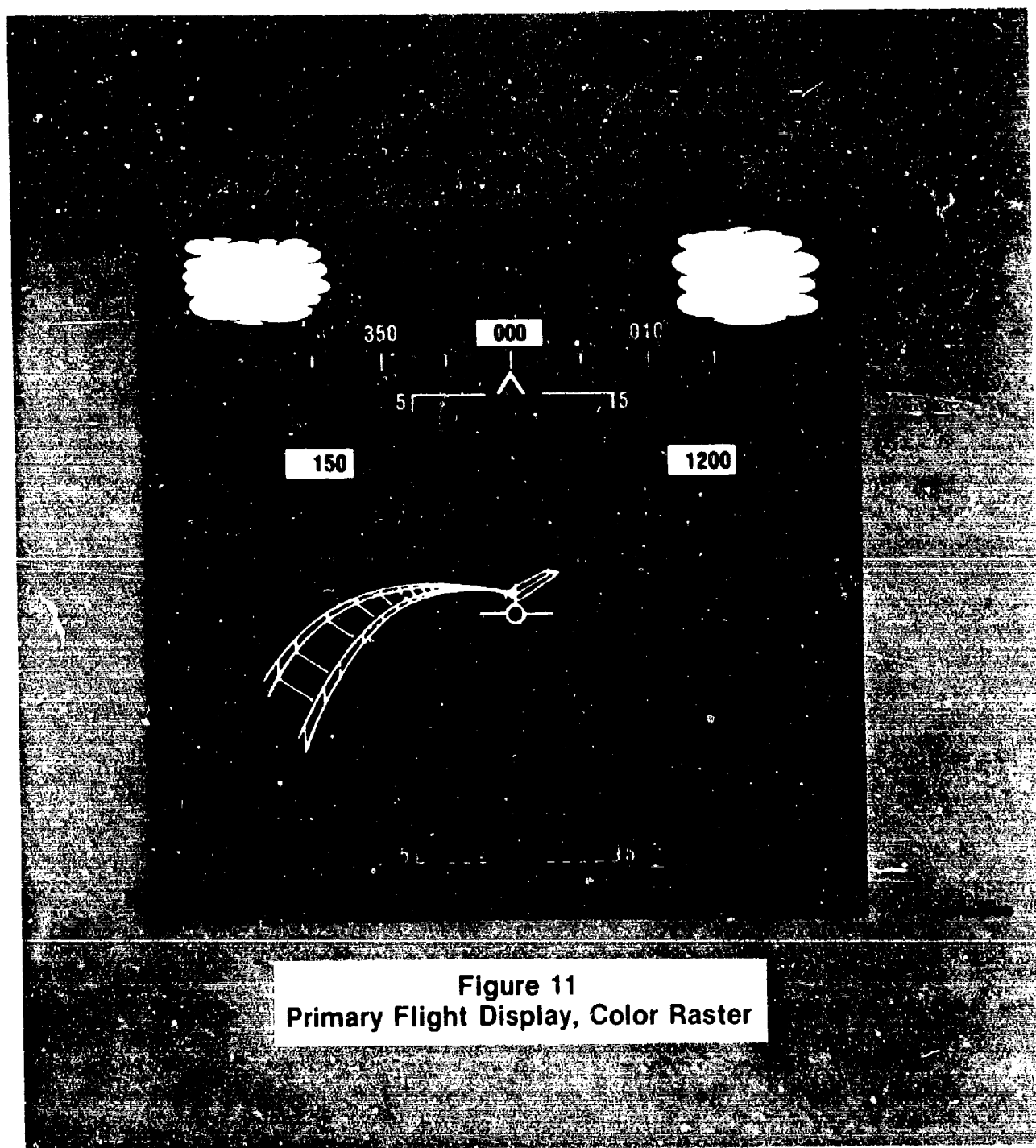


Figure 10
Head Up Format Options: Color Stroke



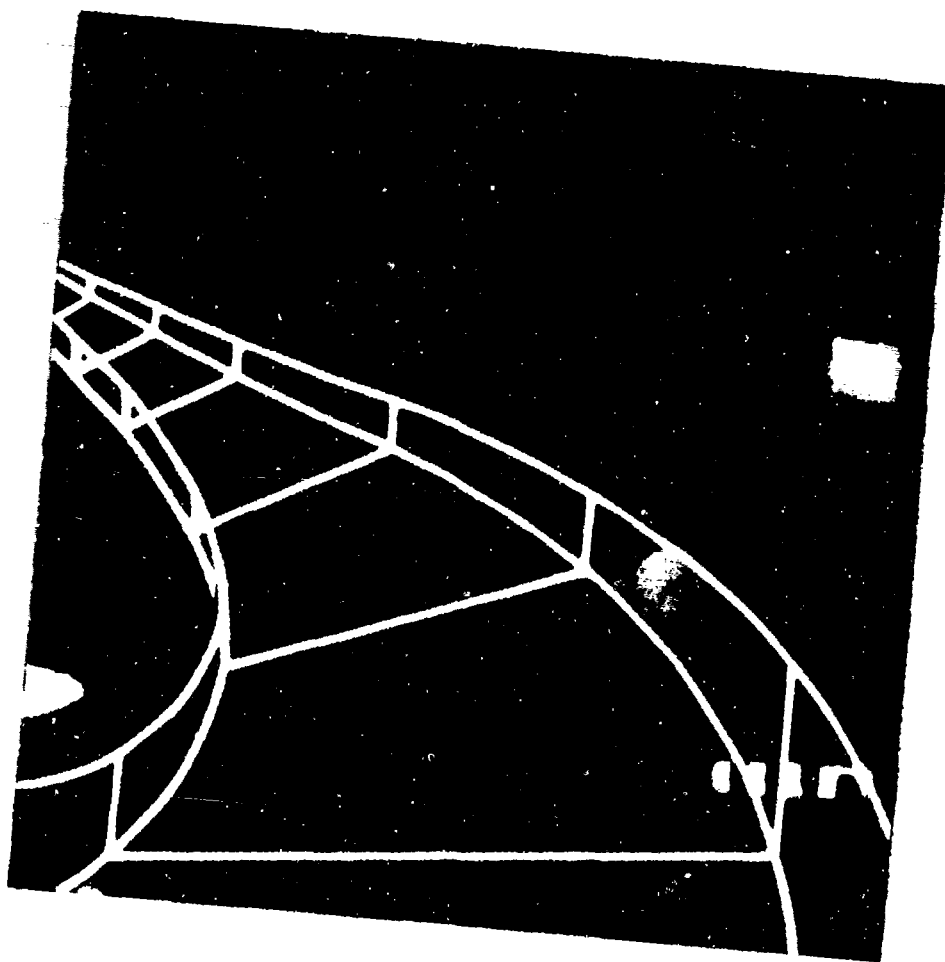
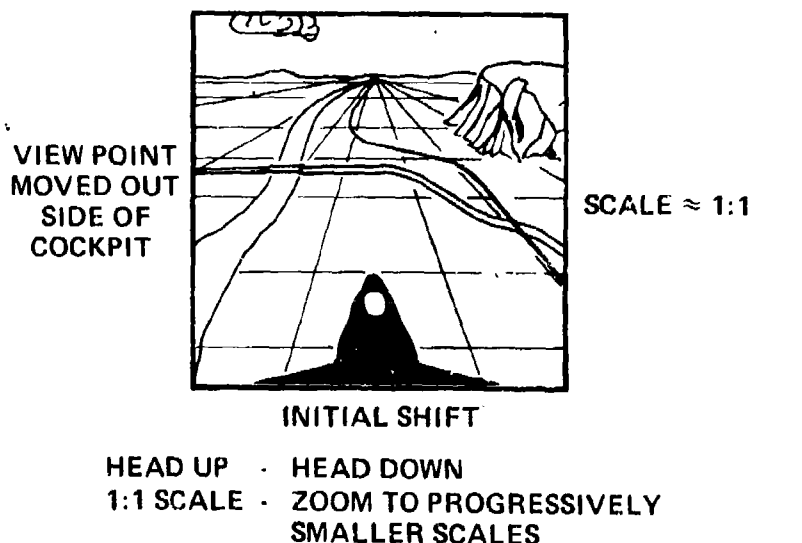


Figure 12
Color Combination Flight Display

2.3 TACTICAL SITUATION DISPLAY TRANSITION

This section contains examples of the monochrome, color stroke and color raster formats that can be used as primary flight displays. They also provide the unique function of allowing the pilot to transition his viewpoint from an inside-out vertical situation one to a pure horizontal, outside-in, tactical situation display, or any point in between. Figure 13 indicates the starting conditions in which the viewpoint has been moved from inside the aircraft to immediately outside, slightly above and to the rear of the cockpit. Scale of this display is approximately 1:1 and a forward view of terrain from this vantage point is shown. As the viewing point shift continues it goes from the position in Figure 13 through the discrete steps shown in Figures 14(a), (b), (c) and (d). In a dynamic situation, the scene would actually zoom out to the birds-eye view as indicated. As the zooming occurs the display scale and the vantage point would change to give the pilot a tactical situation display like a map display. Figure 15 shows the color stroke version of this display. Figure 16 shows a color raster version of this display.

TRANSITION PRIMARY FLIGHT - TACTICAL SITUATION



GP03-0840-20

**Figure 13
Transition**

ZOOM TO "BIRDS EYE" VIEW

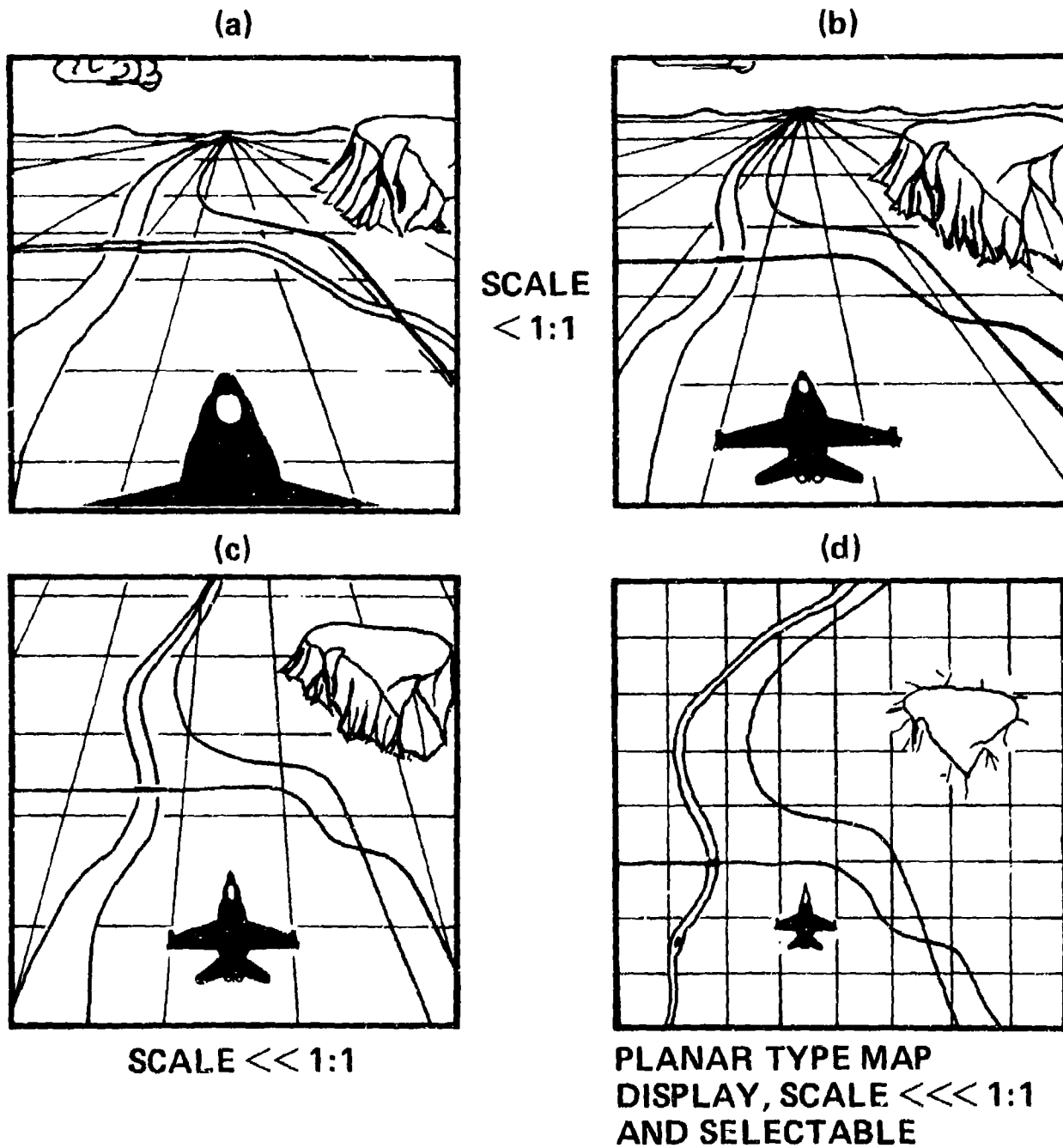


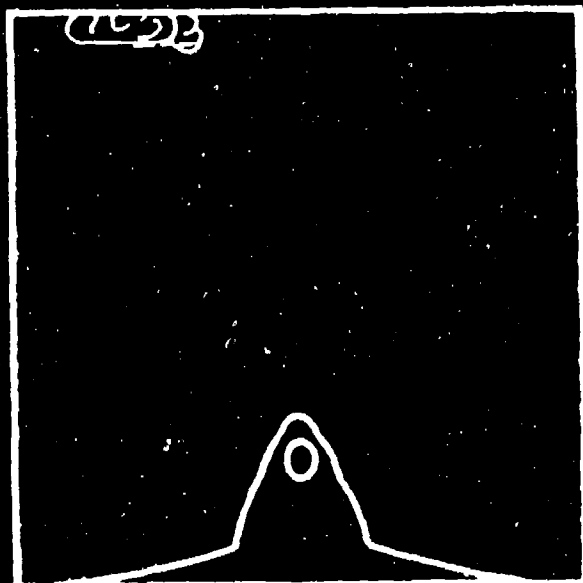
Figure 14
Transition Zoom

GP03-0840-21

TRANSITION

PRIMARY FLIGHT - TACTICAL SITUATION

VIEW POINT
MOVED OUT
SIDE OF
COCKPIT



SCALE \approx 1:1

INITIAL SHIFT

HEAD UP - HEAD DOWN
1:1 SCALE - ZOOM TO PROGRESSIVELY
SMALLER SCALES

GP01 0870-90

Figure 15
Transition: Color Stroke

TRANSITION IN PRIMARY FLIGHT VISUAL SITUATION

VIEW POINT
MOVED OUT
SIDE OF
COCKPIT



SCALE ~ 1:1

INITIAL DRIFT

HEAD UP - HEAD DOWN
1:1 SCALE - ZOOM TO PROGRESSIVELY
SMALLER SCALES

Figure 16
Transition: Color Raster

3. TACTICAL SITUATION DISPLAYS



The basic consideration in formatting tactical situation displays (TSD) is to reduce the presented information to a quantity that the pilot can use. The data is organized by heads-down applications to the aircraft master modes -- navigation, air-to-air, and air-to-ground -- and head-up applications. The tactical situation displays employ highly flexible formats. They have to meet the pilot's functional requirements. They must also supplement the primary flight displays with appropriate data in a perspective view such as the graphic or pictorial terrain formats. A rather simple and yet effective way to reduce

the pilot's workload is to automatically scale the maps as a function of altitude. For example when flying in air-to-air mode normally greater ranges are needed. This is because the pilot is essentially looking up rather than looking down and his vision over the horizon goes to a much greater distance than it does when looking at the ground as in the air-to-surface mode. Therefore, the ranges are biased to greater displayed range, or smaller display scale, when in air-to-air or navigation mode than when in the air-to-surface mode.

Further assistance can be provided by classifying data by type as shown in Figure 17. Mission data, weather data, navigation aids and topographic data all have different applications depending upon the mode, phase of the mission, and pilot preference.

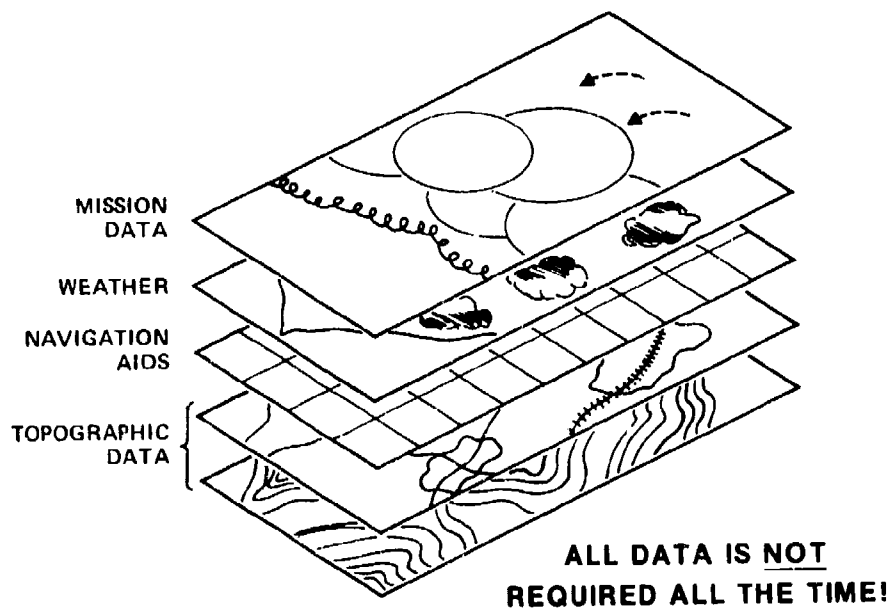
The initial discussion is organized by navigation, air-to-air, and air-to-surface master modes. This is followed by special topographic formats and the application of TSD information to perspective formats. The same general rules and procedures apply for selecting HUD versus head-down formats as were described for the primary flight displays. Standard cartographic symbology was used wherever possible for navigational, topographical, and cultural features on the TSD formats presented here.

These subjects are discussed for monochrome formats and then examples of color stroke and color raster formats are given.

3.1 MONOCHROME DISPLAYS

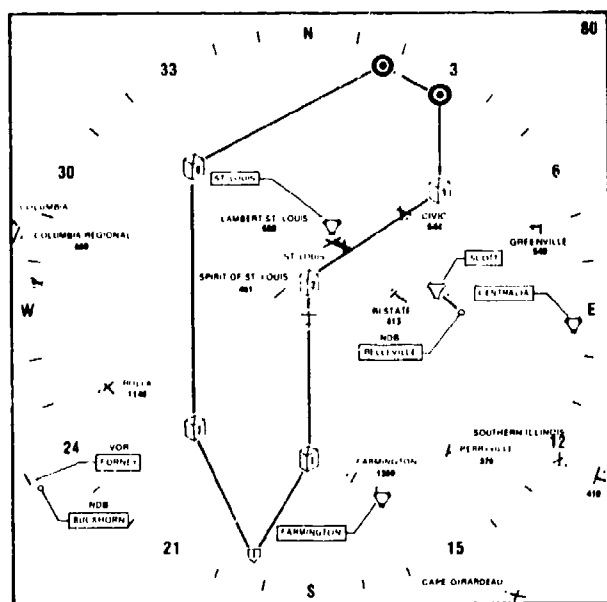
3.1.1 Navigation Mode

In the navigation mode the TSD has been decluttered to provide the pilot with only the pertinent data illustrated in Figure 18. These include way-points, home base, navigation aids, air fields, the aircraft symbol, and a compass rose. The

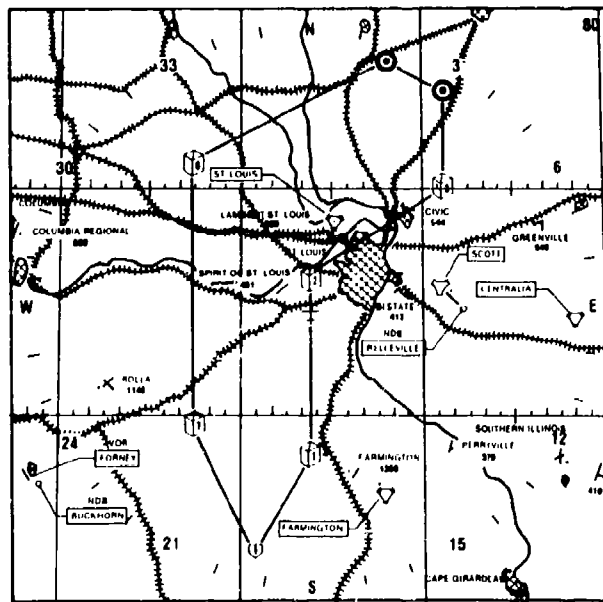


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Figure 17
Information Types



a) DEFAULT DATA



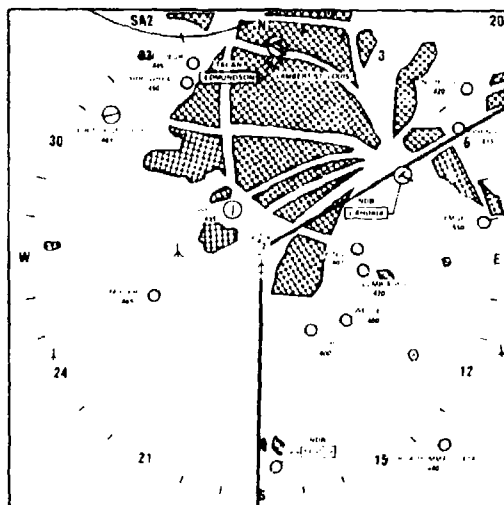
b) EXAMPLE DATA SUPPLEMENTS

Figure 18
High Altitude Navigation Mode Displays
Altitude > 20,000 Ft

GP01-0870-14

"80" in the upper right hand corner of the display indicates the range radius, i.e., range from the center of the display to the edge. This particular display has a 160 nautical mile (NM) total coverage. The items in Figure 18 (a) can be supplemented if selected by pilot, as shown in Figure 18 (b). In this case other navigation aids (i.e., railroad tracks, roads and grid information) are furnished. This declutter capability is particularly important when monochrome displays are used. When flying at lower altitudes (i.e., 5,000-20,000 feet) more detail information of the surface is shown and the scale is increased. As shown in Figure 19, range radius is decreased from 80 to 20 NM and details of city urban grids are included in place of the symbol designations used in Figure 18. These urban grids would be comparable to the lighting grids seen when flying at night or the street grid seen when flying in daylight. Other data such as navigation aids and airports are retained along with the flight path, waypoints, and compass rose.

NAVIGATION MODE 5,000 FT < ALTITUDE < 20,000 FT



DEFAULT DATA

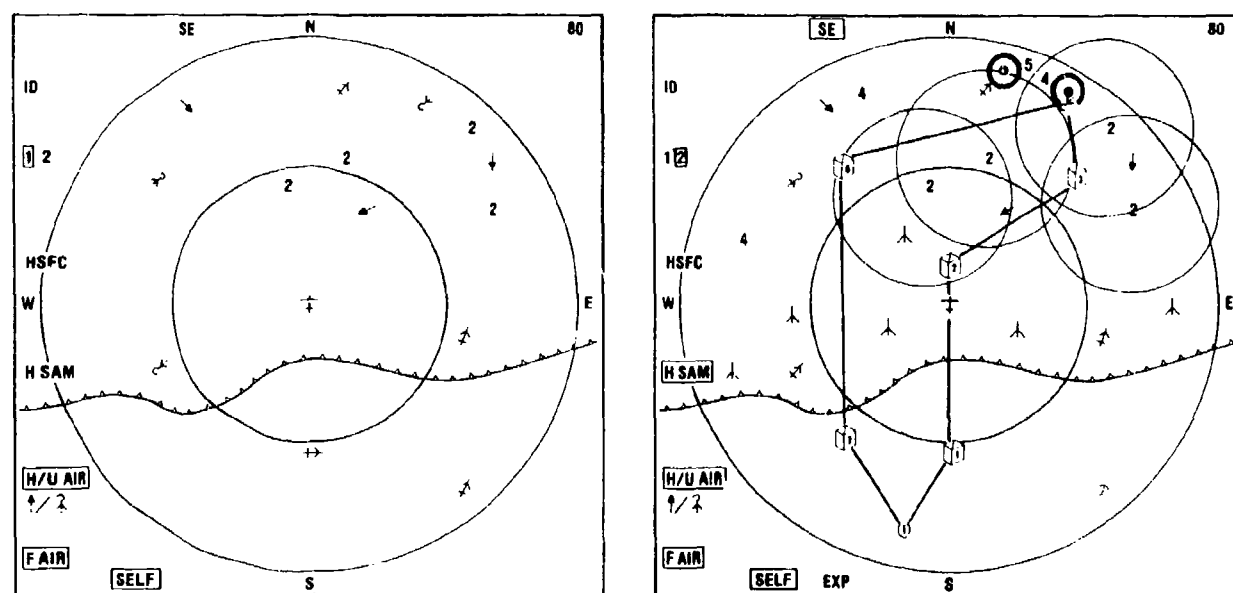
GP01 0870 04

Figure 19
Mid-Altitude Navigation Mode Displays

3.1.2 Air-to-Air Mode

In the air-to-air mode the pilot is not interested in navigation aids as much as he is in the tactical situation concerning other aircraft (threats, unknowns, and friendlies), his position with respect to the Forward Edge of the Battle Area (FEBA), and possibly surface threats. Here we introduce pilot selectable options as shown on the left periphery of the display in Figure 20. Selection of these options could be by peripheral corresponding pushbuttons, touch sensitive displays, cursor designation, or voice actuation. The choices include: level of detail and type of information modes, information types -- hostile surface (HSFC), hostile surface to air missiles (HSAM), or unknown aircraft, and selection or rejection of friendly aircraft data.

In Figure 20 (a) mode 1 is selected. Mode 2 would provide a different menu of options and displayed data, such as weather information. Hostile, unknown, (H/U AIR) and friendly aircraft (F AIR) are displayed, and the display is centered on the aircraft using it as shown by the aircraft symbol in the center. Other versions of this display (not illustrated) could have the display centered around some other point such as a surface threat or another aircraft. The range radius on this display (shown in the upper right corner) is also 80 NM, giving the pilot a good look-ahead capability.



a) DEFAULT DATA

b) TYPICAL ADDITIONAL DATA

KEY:

- | | |
|---------------------|--------------------|
| ✂ Unknown aircraft | 2 Hostile Sam type |
| ↑ Hostile aircraft | Waypoint |
| ± Own aircraft | Target |
| ✂ Friendly aircraft | FEBA |

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Figure 20
Air-to-Air Situation Displays

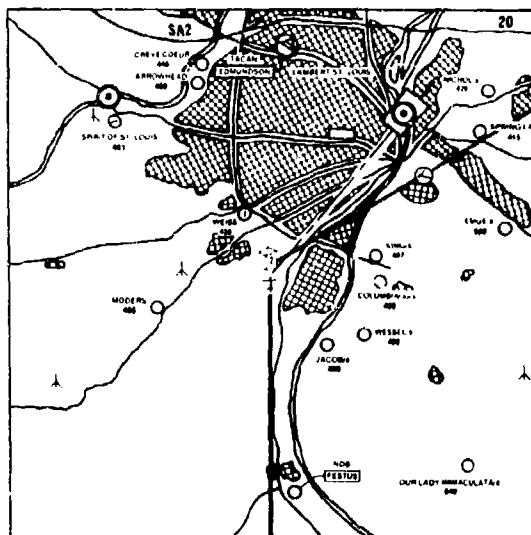
In Figure 20 (b) hostile surface to air missile (SAM) sites are displayed as a result of the pilot selecting HSAM. Selection of the SAM envelope option (SE) displays SAM maximum ranges as indicated by the circle surrounding the type of SAM. The identification option (ID) is not used in Figure 20 (a) or (b) but would present altitude, number, and type of aircraft for each hostile and unknown target. The expand option (EXP) would permit a scale change around a designated point other than self. A flight path is included for proceeding through various waypoints and approaching the two targets as indicated in the upper center of the display. This display would be used during a surface strike mission ingress when the pilot is concerned about his penetration capabilities through surface and airborne threats.

3.1.3 Air-to-Surface Mode

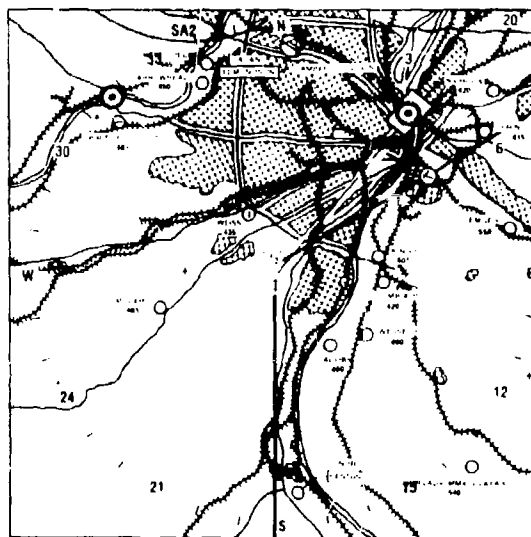
The air-to-surface mode is very similar to the navigation mode. In Figure 21 the conditions for an altitude between 5,000-20,000 feet are illustrated. The basic display is similar to the navigation display. The major addition is flight track, sensor line-of-sight, sensor footprint, and surface threats. Also indicated are primary and alternate targets. The data can be expanded as shown in Figure 21 (b). This is similar to the expanded data when in the navigation mode.

AIR-TO-GROUND MODE

5,000 FT < ALTITUDE < 20,000 FT



a) DEFAULT DATA



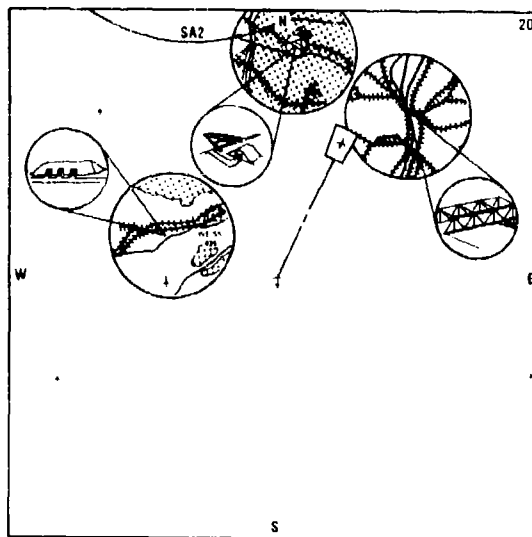
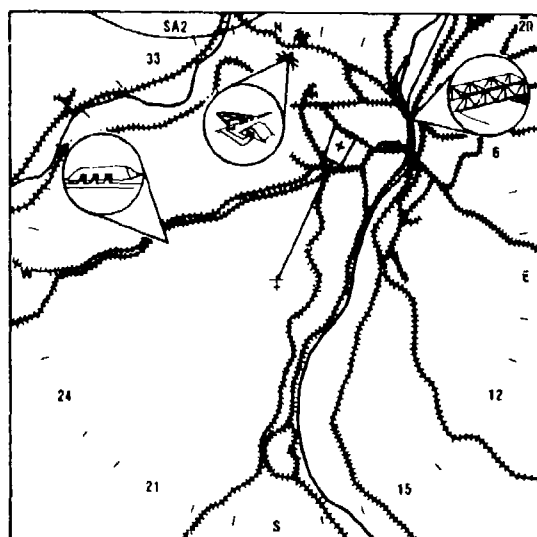
b) EXAMPLE DATA EXPANSION

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Figure 21
Air-to-Ground Situation Displays

Figure 22 illustrates some alternative formats that highlight conditions in the target area. They can be used to "spotlight" the target by expanding detail within the target area. They can also show the general peripheral condition in the whole map region and supplement that with an illustration of the target to assist the pilot in identifying it. Sensor footprint and line-of-sight to the aircraft symbol are retained so that the pilot can readily correlate the TSD with sensor displays which would also be available to him.

The air-to-ground mode for very low altitudes (under 5000 feet) is illustrated in Figure 23. The map scale is very large, typically on the order of 1:25,000. More detailed pictorial symbology can be readily inserted on such a map to assist the pilot in finding features such as bridges, or obstacles such as transmission towers and radio transmitting towers. Pictorial symbology is best suited to features, e.g., gas stations and dams, and can also be used with more conventional topographical map symbology such as schools or cemeteries.



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Figure 22
Air-to-Ground Situation Display Targets Highlighted

At this large scale the origin of surface threats might well be off the display. In fact, the aircraft could be inside a threat envelope and not have either the limit or center of the threat envelope shown on the display. Therefore, alpha-numerics are required for monochrome and color stroke formats to designate threat type and some cue as to the boundary of the threat envelope or the threat location even though not on the display. Color raster formats can fill the background in red or yellow to denote a presence inside a threat envelope when the map scale prevents showing the normal cues.

3.1.4 Special Topographic Formats

The primary tactical interest in topography by the pilot is illustrated in Figure 24. This is expressed in the following questions. What terrain can be seen from different altitudes? How am I masked from surface threats or surface ground control intercept (GCI) radars? How much terrain clearance is available in conjunction with threat masking conditions? Are there any safe tunnels where I can both avoid the terrain and stay below the threats' acquisition radars? The answers to these questions are displayed as contours on a map as shown in Figures 25, 26 and 27. The contours at three altitudes are given.

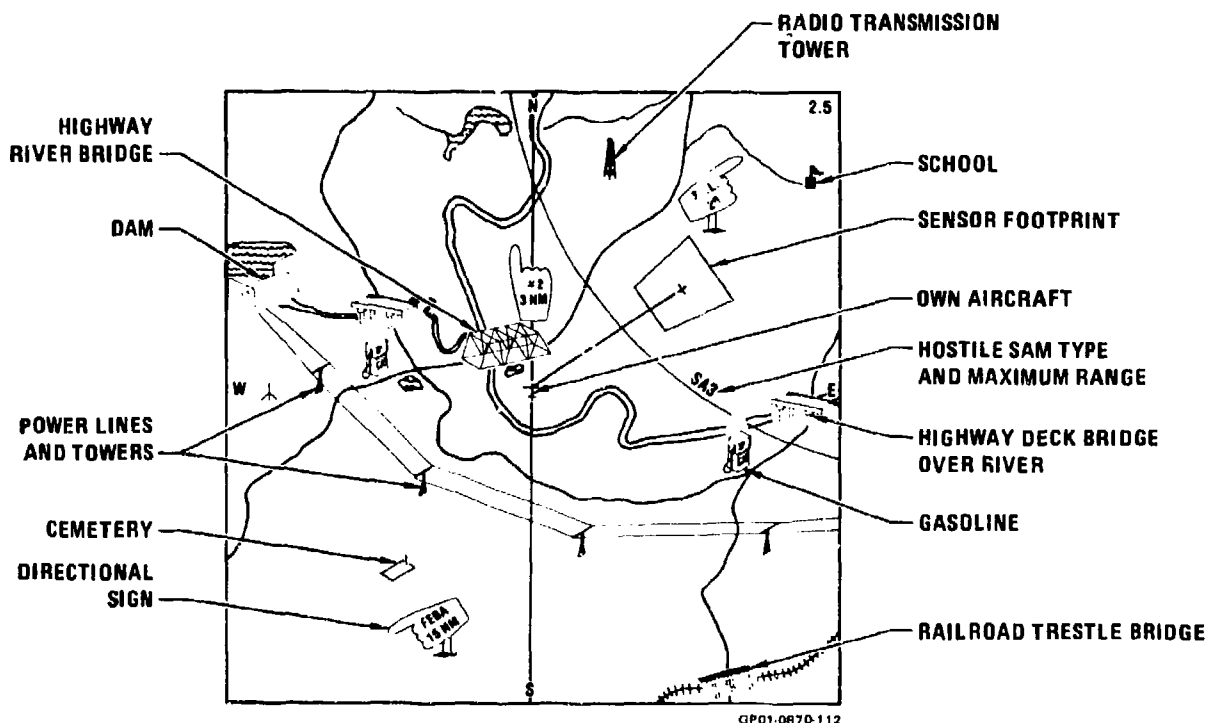


Figure 23
Air-to-Ground Low Altitude Situation Display
Altitude < 5,000 ft

SPECIAL TOPOGRAPHIC FORMATS

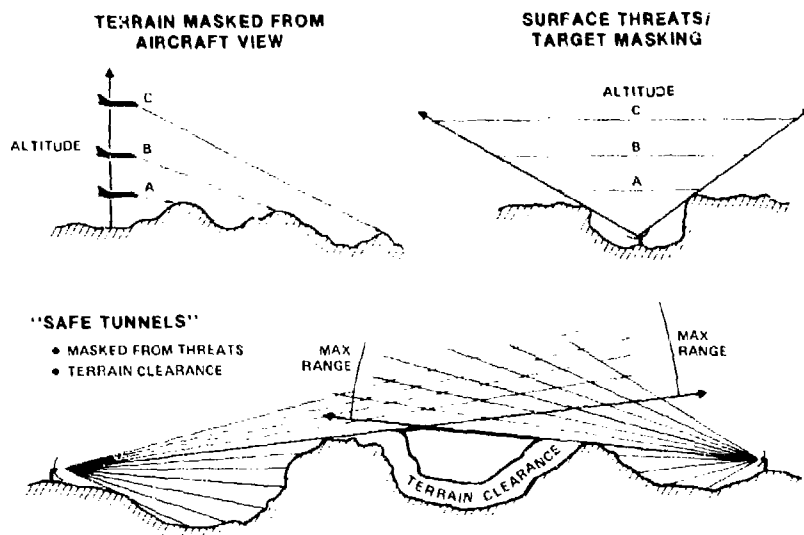


Figure 24
Terrain Feature Utilization

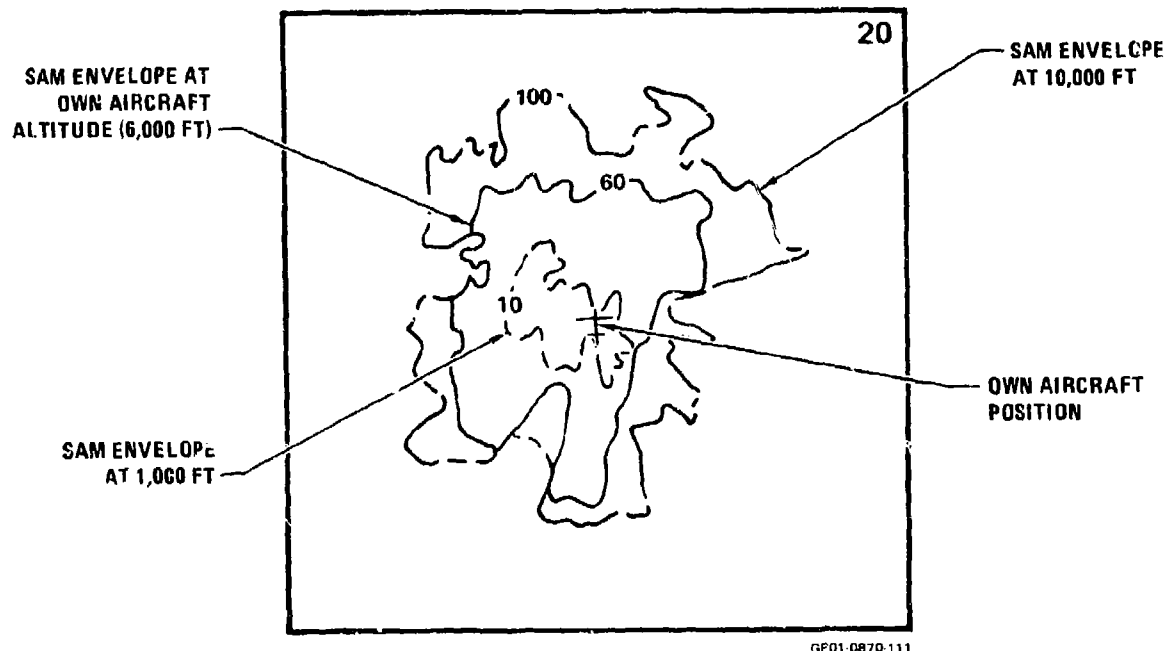


Figure 25
Visibility Limits

SURFACE THREAT LIMITS

MASKING ALTITUDES
MAX RANGE

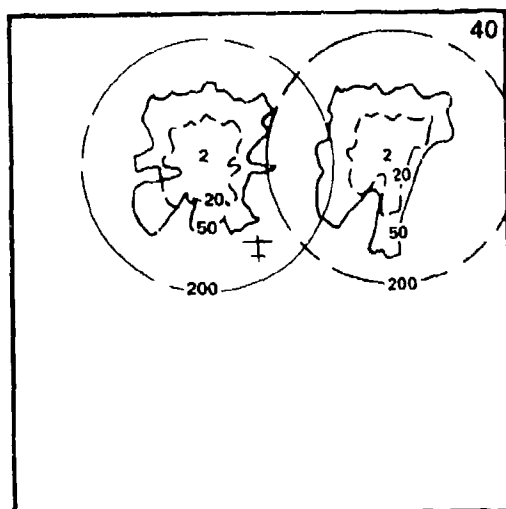
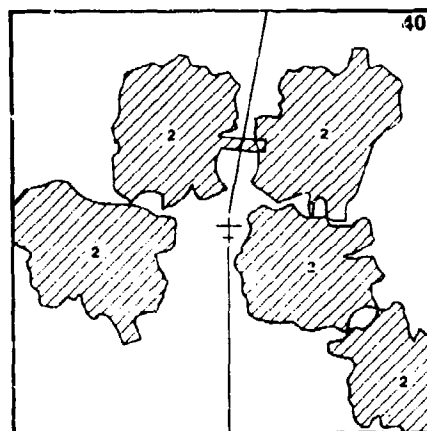


Figure 26
Surface Threat Limits

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HIGH RISK AREAS

THREAT MASKING
AND TERRAIN CLEARANCE
NOT AVAILABLE



CLEAR AREA - "SAFE TUNNELS"

GP01 0870 23

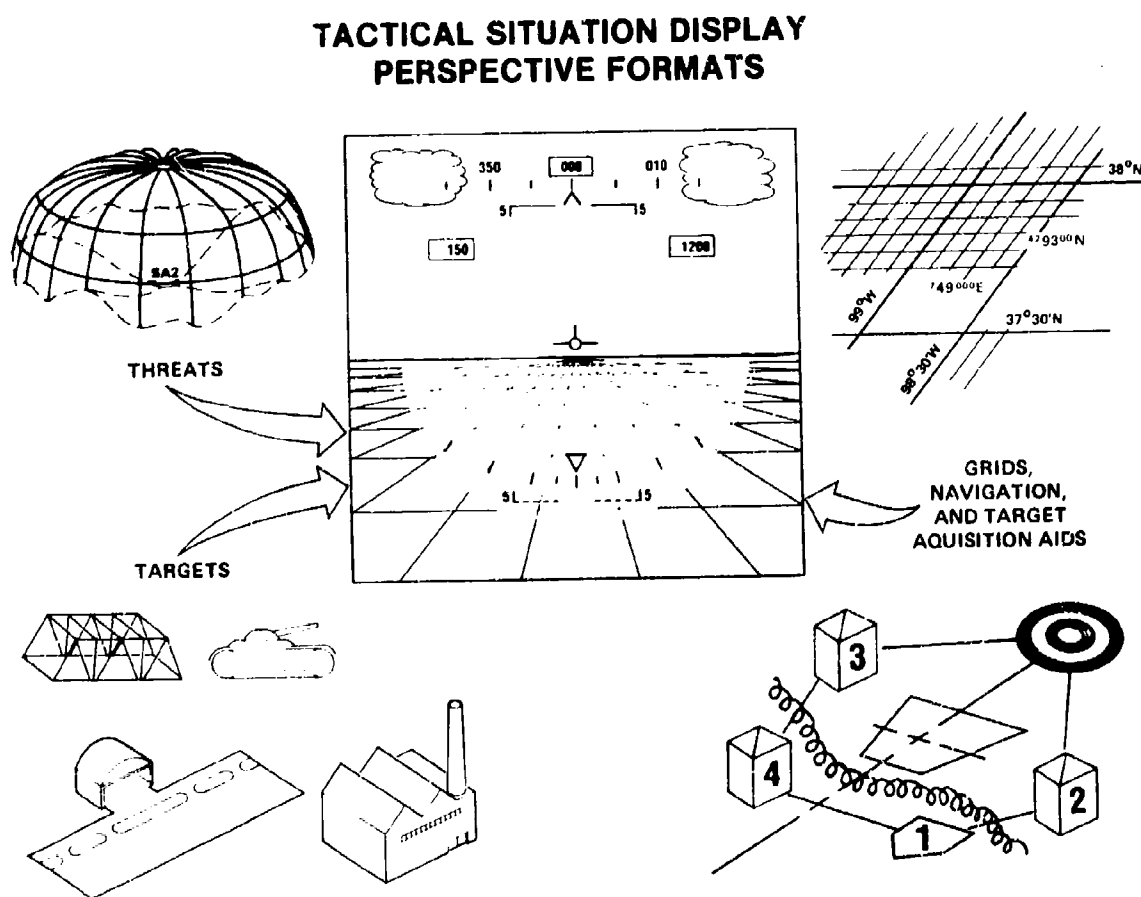
Figure 27
Threat High Risk Areas

The visibility limits displayed in Figure 25 show how far the pilot or aircraft sensors can see from a given altitude. It should be noted that if the aircraft can see the ground from within any contour line, it is obvious that the aircraft can be seen from that ground position. The aircraft is not masked in that contoured area from a threat or acquisition radar. The numbers associated with each contour indicate altitudes in hundreds of feet. In this example the smallest contour is what would be visible from a 1000 foot altitude. The next contour is at 6000 feet and corresponds to the aircraft's current altitude. It would change according to aircraft altitude. The third contour is shown at 10,000 ft. The pilot has information to allow him to relate, or trade off, altitude for survivability. This concept is reversed in Figure 26. Here the visibility from a surface threat to certain altitudes is displayed. In this case, it is assumed that a SA-2 is centered in each of the locations depicted by the numeral 2 in the figure. The SAMs can see out to the first contour for aircraft flying at 2000 ft altitude. The second contour at 5000 ft altitude is the aircraft's current altitude. The 20,000 ft circle indicates the maximum range of the missile. Contours and SAM ranges are unique to each type, location and terrain. As with previous TSDs the range scale is given by the numeral in the upper right hand corner of the display and your position is given by the aircraft symbol in the center of the display.

Figure 27 indicates a combination of visibility and terrain clearance. The cross-hatched areas are those in which the threat has a line-of-sight available to altitudes above which there is no terrain clearance. The non-cross-hatched areas provide both terrain clearance and masking from the threats. These areas are fully safe "corridors", or tunnels, through which the pilot can fly. If he increases his altitude the acquisition range of the surface threats can extend, causing the cross-hatched areas to grow.

3.1.5 TSD Perspective Formats

One of the advantages of pictorial formats in a heads-up atmosphere is that they can transfer extensive, properly oriented, tactical situation data to the pilot. Tactical information such as threats, targets, flight paths, FEBA, grid lines, and navigation aids can all be superimposed on the primary flight display. This concept is illustrated in Figure 28.



**Figure 28
TSD Perspective Formats**

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One of the prime concerns of the pilot is surface threat envelopes. These can also be superimposed onto the perspective display as used for the primary flight display. An example of this is shown in Figure 29. In this example a graphic terrain format serves as the primary flight display for a pilot flying VFR, or free flight mode. The SA-2 threat envelope appears shadowed by the ridge line and has a maximum range which the pilot is approaching. Because the threat location is beyond the ridge (over the local horizon) it is not possible to place the threat identification at its origin on the ground and still have it visible. Therefore, the SA-2 designation is provided in the upper left hand corner but still in the threat envelope. Definition of the threat envelope is dependent upon programs such as Purple Haze* which will provide the parameters for generating such displays.

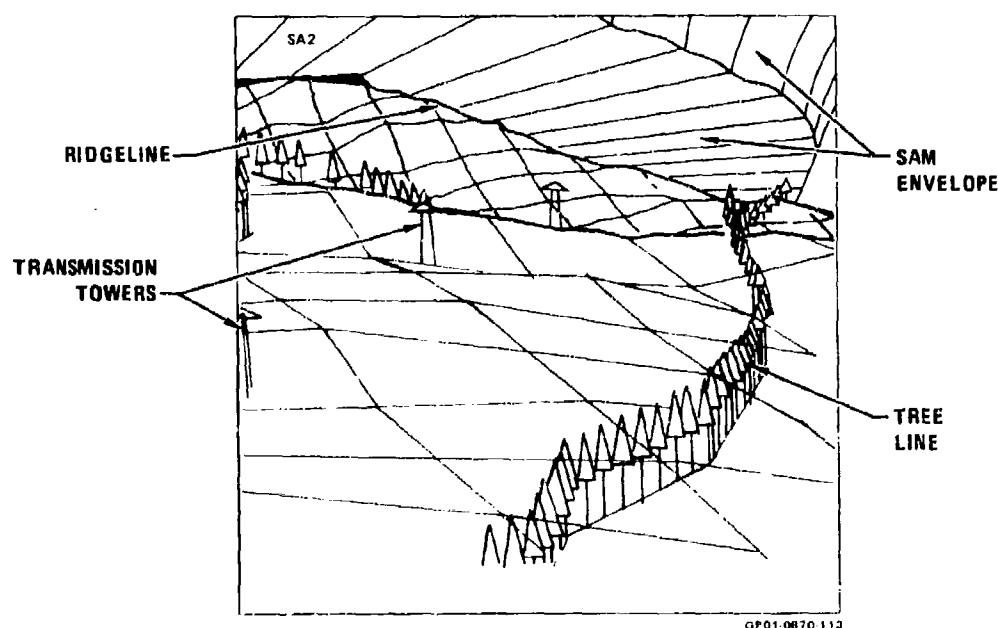


Figure 29
Threat Envelope with Graphic Terrain Data

Another example of this is illustrated in Figure 30 in which line graphic terrain data is supplemented with a flight path. Here flight waypoints (milestones) are shown as well as the threat envelope.

3.2 COLOR STROKE FORMATS

These formats are the same as the monochrome formats previously described, only color has been added to each of the strokes. Consistency with the primary flight display has been retained when possible. In Figure 31, for example, the aircraft symbol is white indicating a self-designation. The orange coloring of the compass rose and the airfields indicates a range of items available. Other color coding is based on standard color flight charts available today.

* Purple Haze is an ongoing Air Force sponsored program whose goal is to provide the aircrew with a flight path having the highest probability of survival through ground threat envelopes. The program is developing the algorithms necessary to generate the information for displaying Purple Haze data to the aircrew.

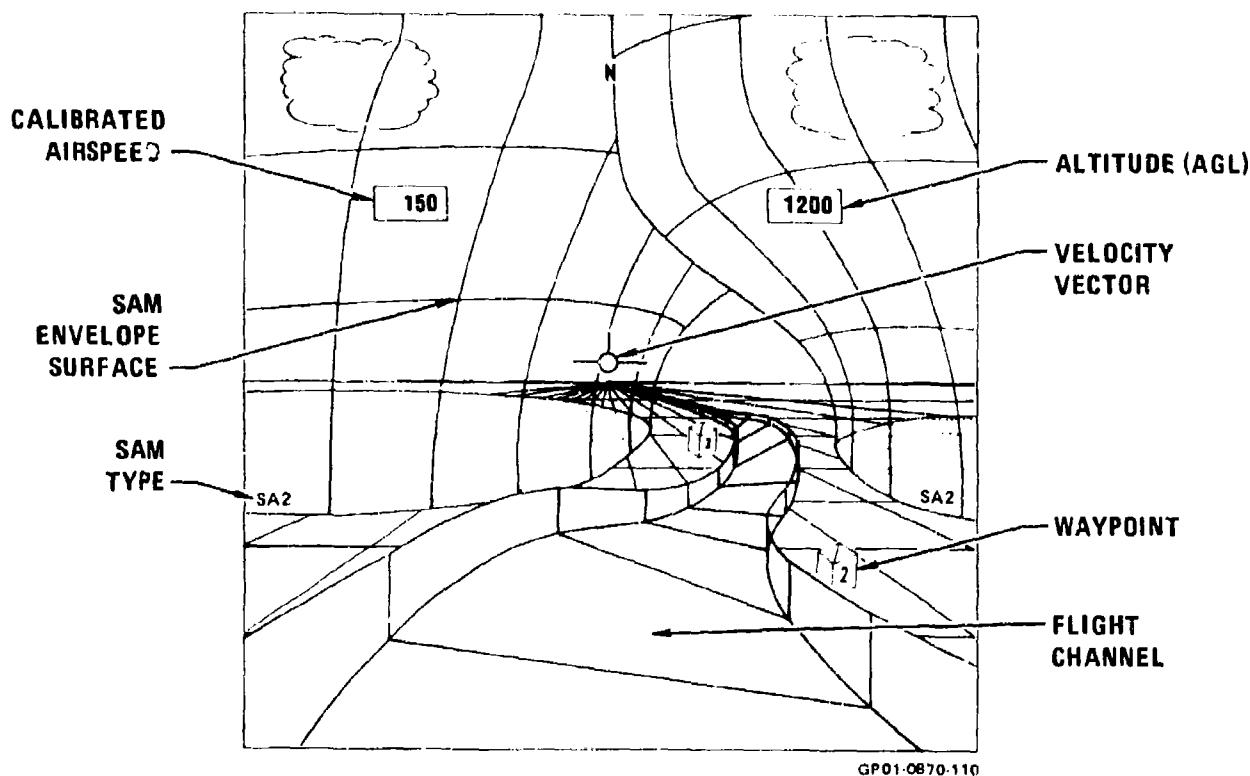


Figure 30
Primary Flight and Tactical Situation Data

The air-to-air mode data depicted in Figure 32 follows the convention that hostiles are red, friendlies green, and unknowns yellow. Self designation is white, and scale information such as the range scale is orange.

Figure 33 shows a color stroke version of the air-to-ground mode.

In Figure 34 the visible terrain limits from the aircraft are shown by their color coding. The 6000 ft altitude contour is dashed with white to associate it with the aircraft's current altitude and the white aircraft symbol. Figure 35 also designate the current altitude contours with a white dashed line. In Figure 35 the status of each threat is denoted by red. The red is an active threat. If the threat were shown in yellow it would indicate a known threat site but one that is either not tracking or active. The aircraft symbol in Figure 36 is white and the danger areas represented by the threat areas are red cross-hatched to indicate danger -- do not enter.

Figure 37 employs the brown ground grid and green trees. The SA-2 threat envelope is red lined. Peripheral data, namely the transmission towers, are orange. In Figure 38 the flight path is violet as it has been in the other tactical situation and primary flight displays. The clouds are white, and aircraft designated data -- altitude, and airspeed -- are white.

3.3 COLOR RASTER FORMATS

Color raster formats for the map-type displays are very similar to the color stroke except that fill is provided for certain symbology characteristics. The navigation mode is illustrated in Figure 39 for altitudes above 20,000 ft.

In Figure 40A the air-to-air mode is shown supplemented with radar coverages and A/A missile limitations for a threat aircraft and your own weapon system. Your own coverage is in white to prevent confuzing it with the threat's envelopes. The border between R_{MAX1} and R_{MAX2} missile ranges is lined with yellow and red. The border between R_{MIN} and R_{MAX2} is lined with green and yellow. The threat envelope is filled yellow, red, and green, corresponding to R_{MAX1} , R_{MAX2} and R_{MIN} regions. Figure 40B shows a similar situation, but with two threats' and your own radar coverages. In areas of overlap the priorities for fill are red, then yellow and then green. A similar capability could be provided with colored lines in the color stroke mode. However, it would not be nearly as effective because the lines would tend to run together and be confuzing as to which lines belong to which threat.

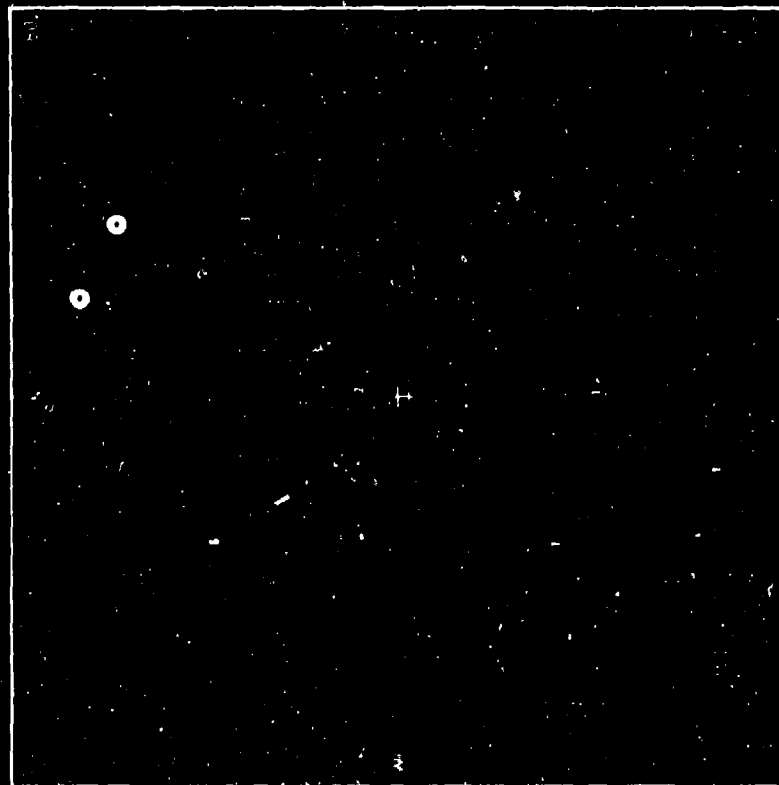
In the air-to-ground mode depicted in Figure 41, the symbology is filled with color to take advantage of the color raster capability. Figure 41A depicts the situation display with certain target areas highlighted. This format provides greater detail of specific pilot selectable (i.e., cursor designation, touch sensitive display, coordinates, voice actuation) targets or map areas without losing the positional context afforded by the larger scale of the overall map display.

In Figure 42 the surface threat boundaries are indicated in color. The lighter color indicates less intense danger from threat. The darker color indicates greater threat danger as you approach the threat and have less opportunity to use terrain masking or maneuver. Similar restrictions are used in Figure 43 where activity of the threat is designated with the color red or yellow, red being more dangerous. The self-designation aircraft symbol is white.

Figures 44 and 45 illustrate how color raster is used on perspective display formats giving both threat envelopes and primary flight data.

NAVIGATION MODE

ALTITUDE > 20,000 FT



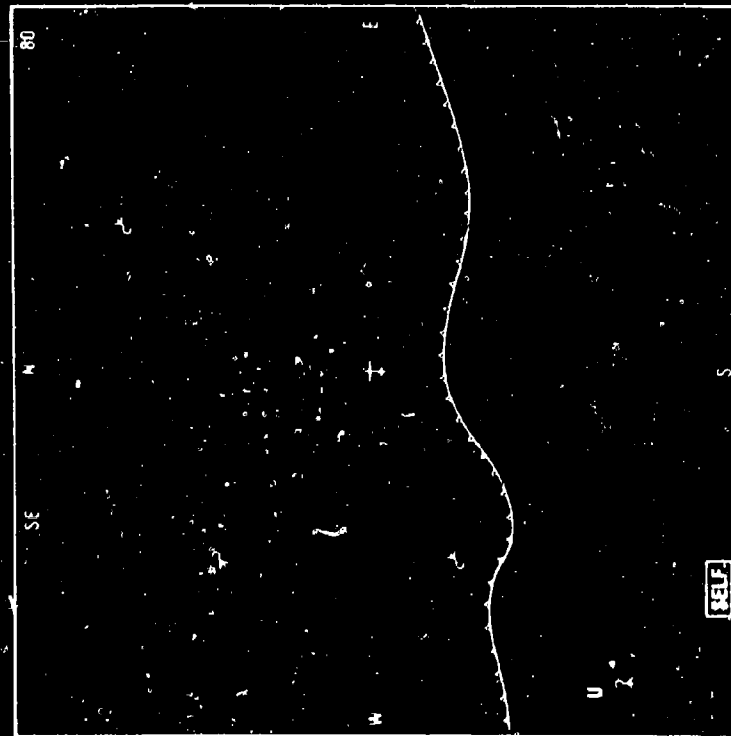
DEFAULT DATA



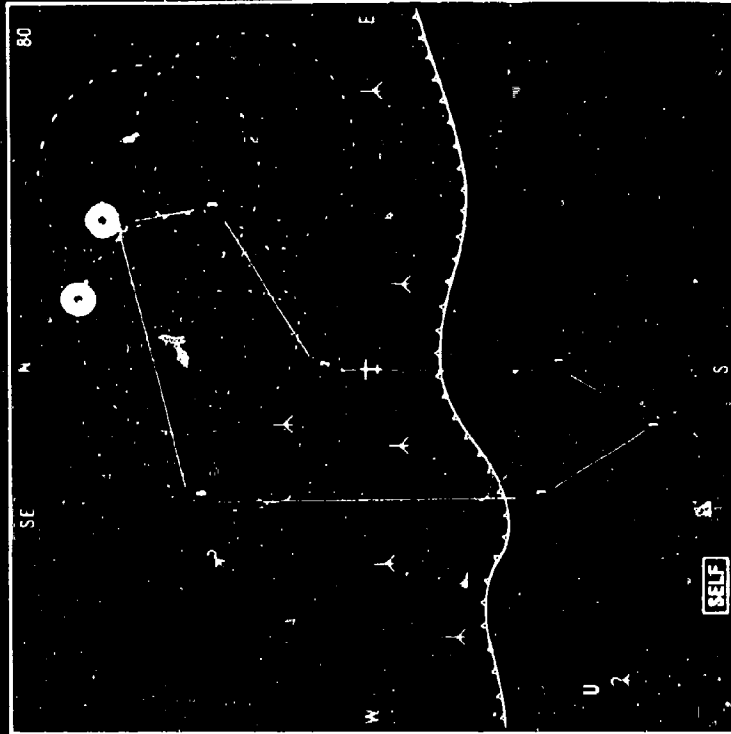
EXAMPLE DATA SUPPLEMENTS

Figure 31
High Altitude Navigation Mode Displays:
Color Stroke

AIR-TO-AIR MODE ALTITUDE > 20,000 FT



DEFAULT DATA



TYPICAL ADDITIONAL DATA

Figure 32
Air-to-Air Situation Displays: Color Stroke

AIR-TO-GROUND MODE
5,000 FT < ALTITUDE < 20,000 FT



Figure 33
Air-to-Ground Situation Display: Color Stroke

TERRAIN VISIBILITY LIMITS FROM AIRCRAFT ALTITUDES

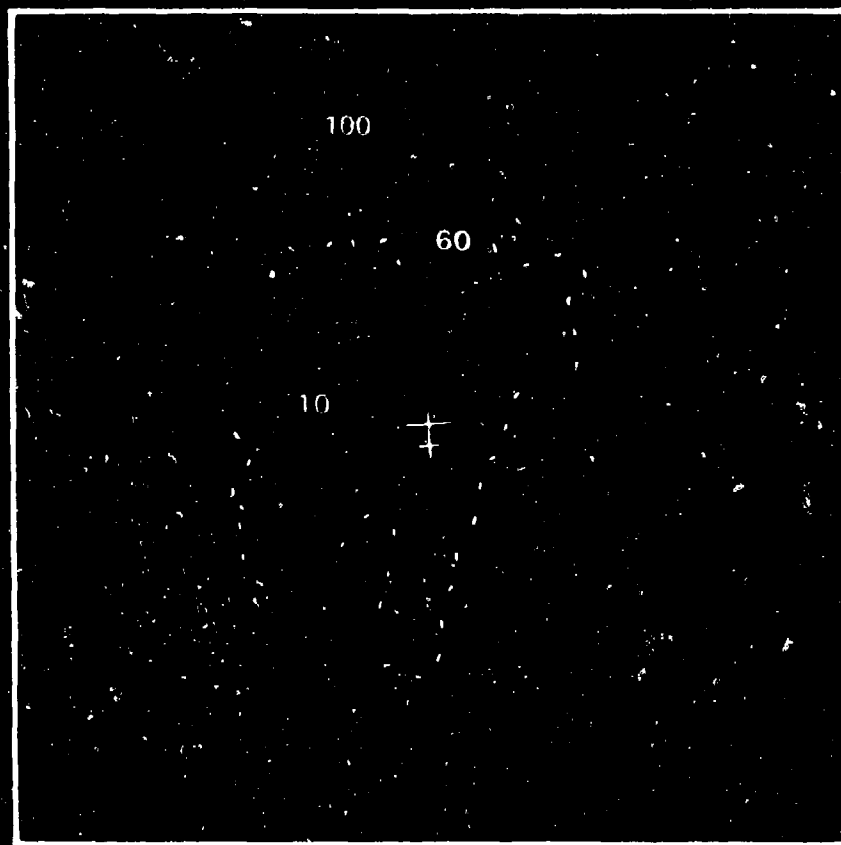


Figure 34
Visibility Limits: Color Stroke

SURFACE THREAT LIMITS

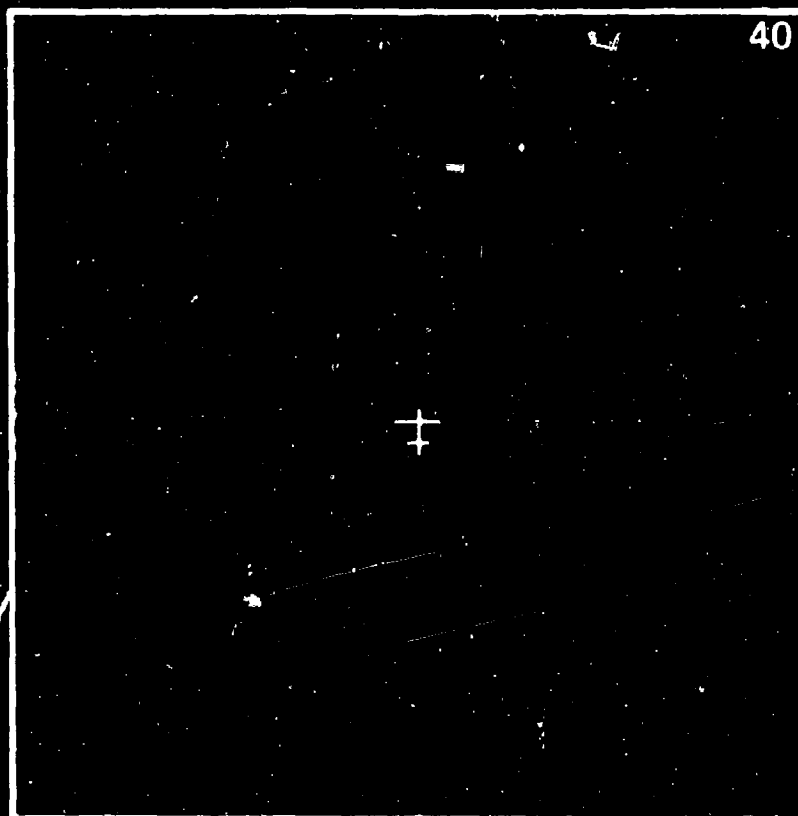
MASKING ALTITUDES

MAX RANGE



Figure 35
Surface Threat Limits: Color Stroke

HIGH RISK AREAS
THREAT MASKING
AND TERRAIN CLEARANCE
NOT AVAILABLE



CLEAR AREA - "SAFE TUNNELS"

Figure 36
Threat High Risk Areas: Color Stroke



Figure 37
Threat Envelope with Graphic Terrain Data:
Color Stroke

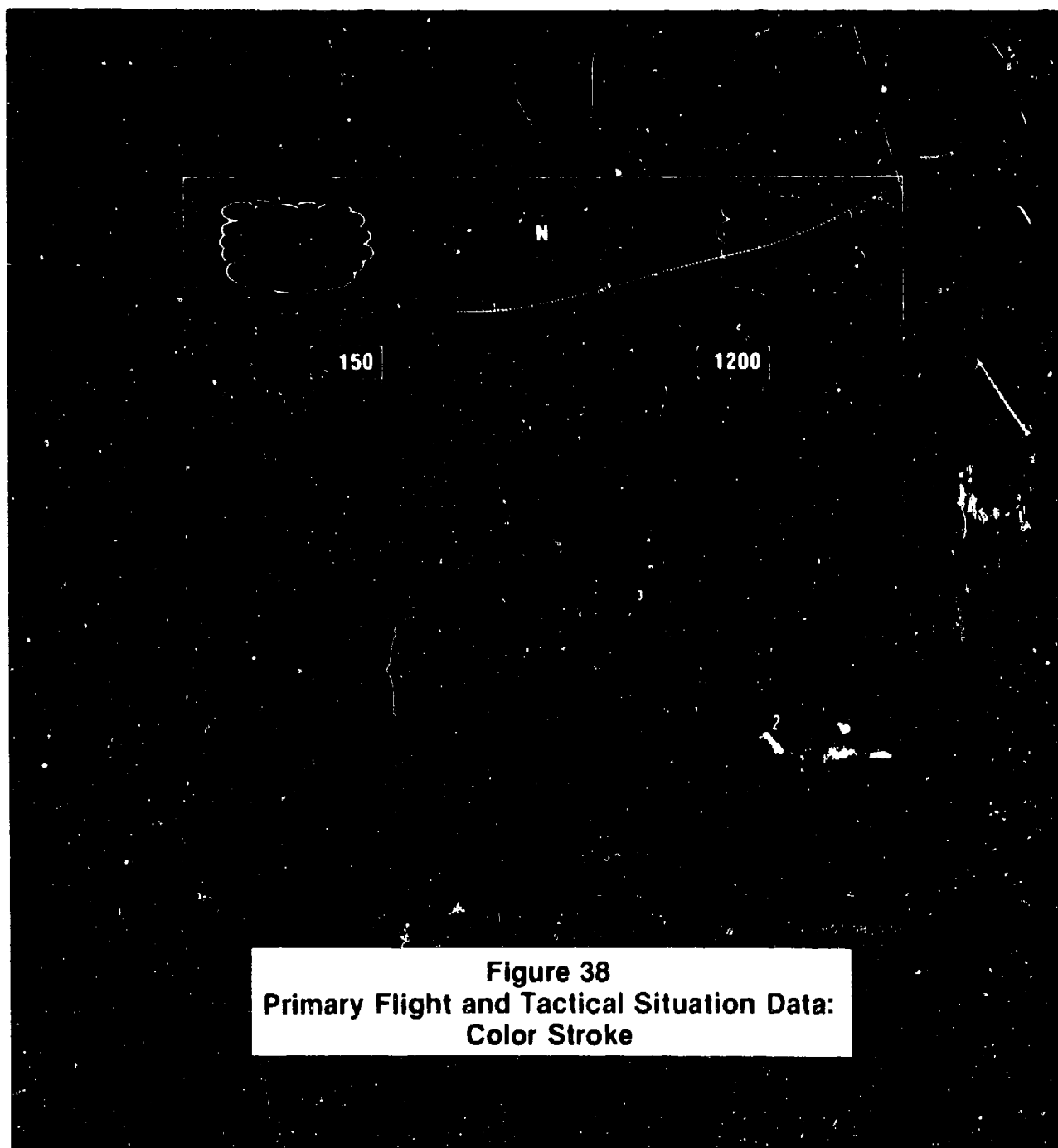
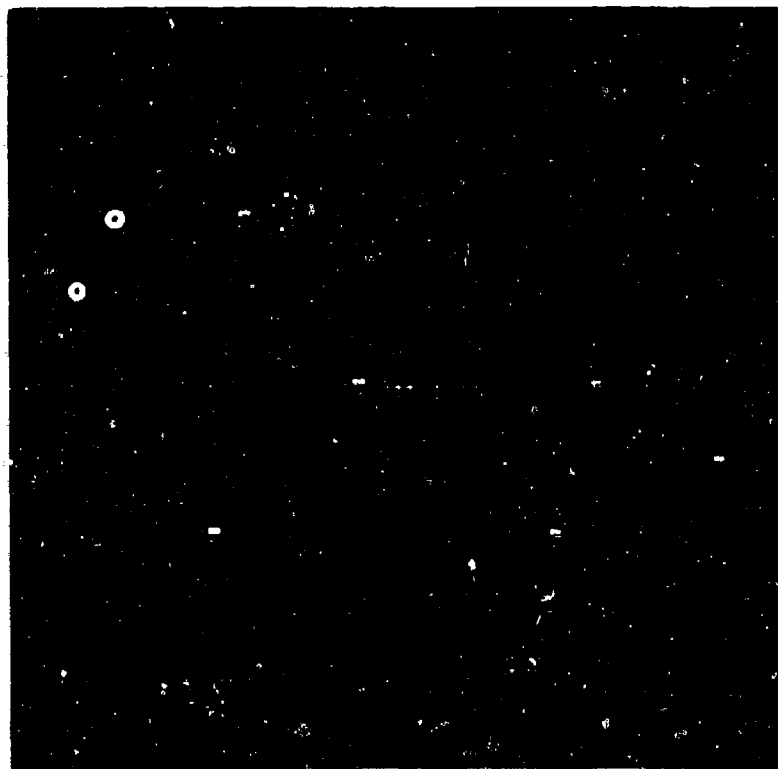
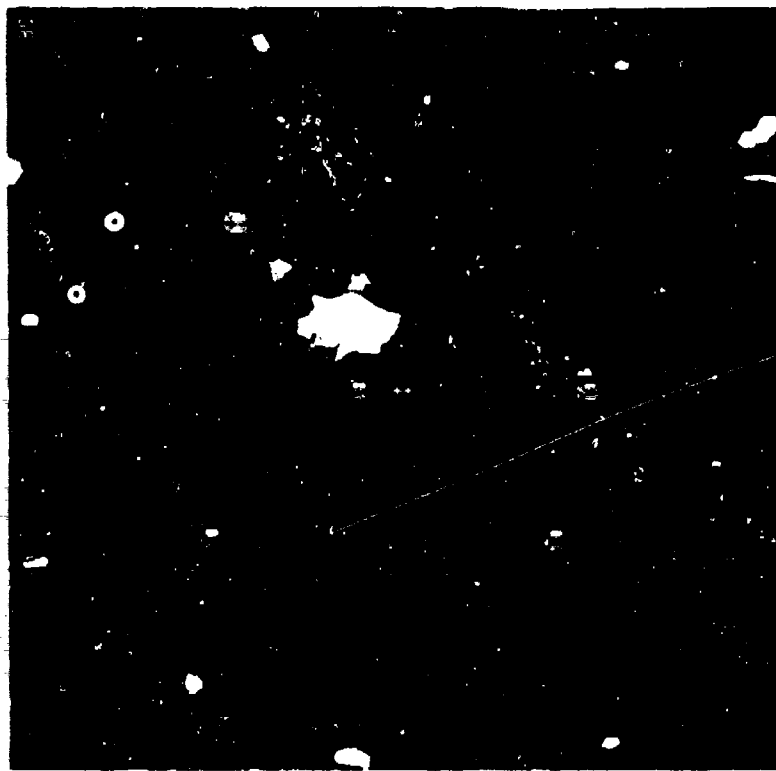


Figure 38
Primary Flight and Tactical Situation Data:
Color Stroke

NAVIGATION MODE ALTITUDE > 20,000 FT



DEFAULT DATA



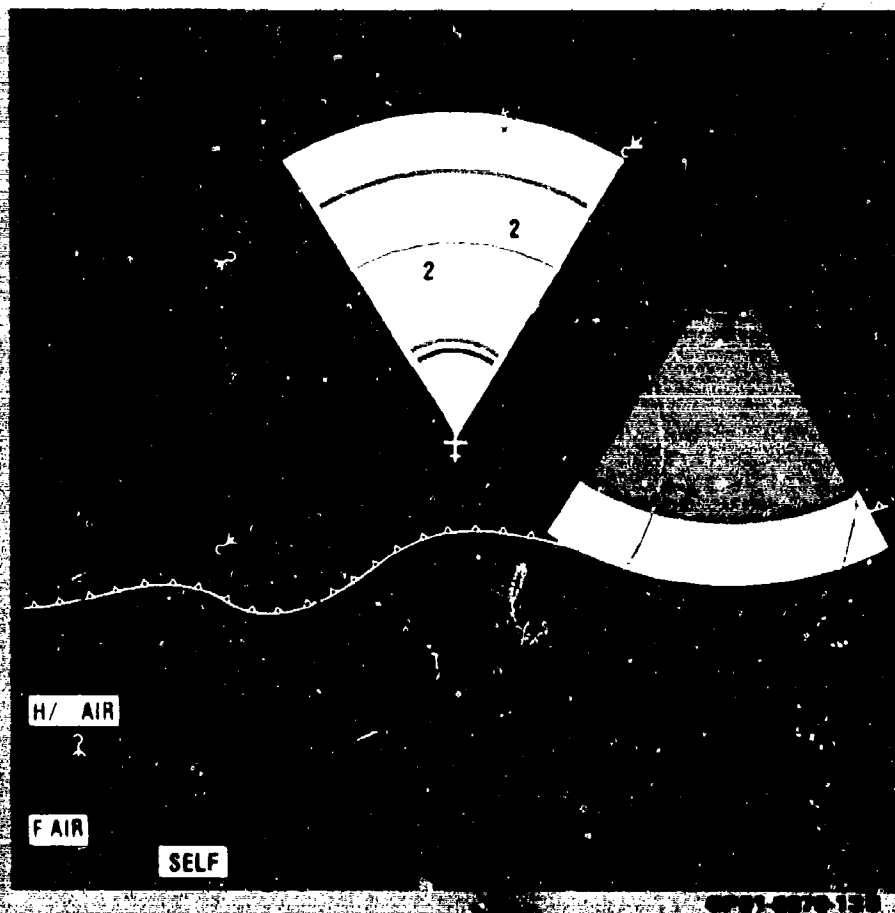
EXAMPLE DATA SUPPLEMENTS

Figure 39
High Altitude Navigation Mode Displays:
Color Raster

CSN1 007A 1-1-

AIR-TO-AIR MODE

ALTITUDE > 20,000 FT



DEFAULT DATA

Figure 40A
Air-to-Ground Situation Display: Color Raster

AIR-TO-AIR MODE

ALTITUDE > 20,000 FT



Figure 40B
Air-to-Air Situation Display: Color Raster

AIR-TO-GROUND M...
5,000 FT < ALTITUDE < 20

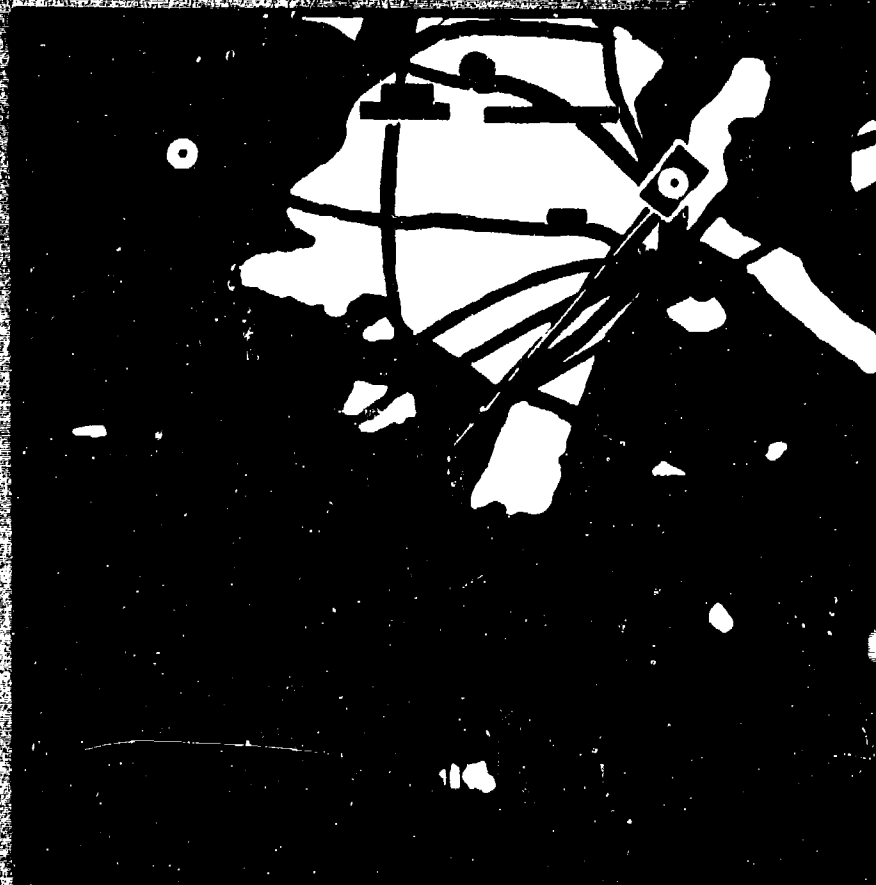


Figure 41
Air-to-Ground Situation Display: Color Raster

**ALTERNATES
AIR-TO-GROUND MODE
AT 5,000 TO 20,000 FT**

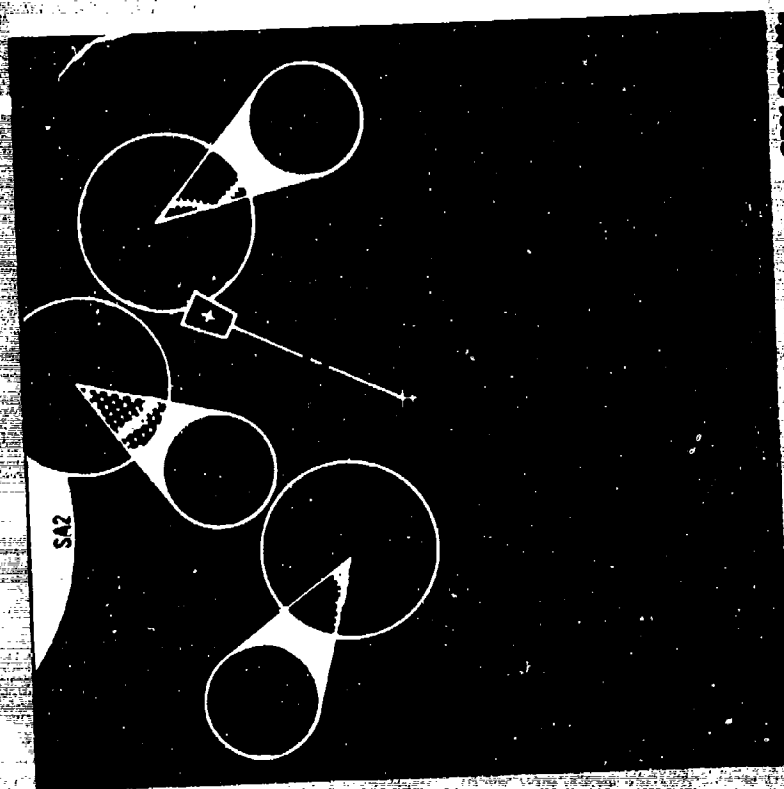
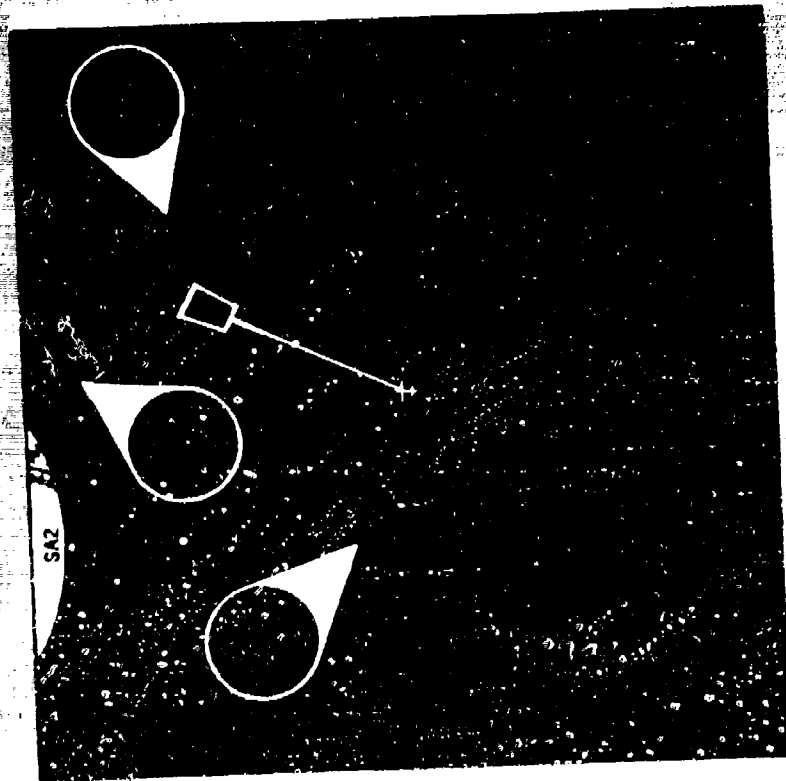


Figure 41A
Air-to-Ground Situation Display with
Targets Highlighted: Color Raster

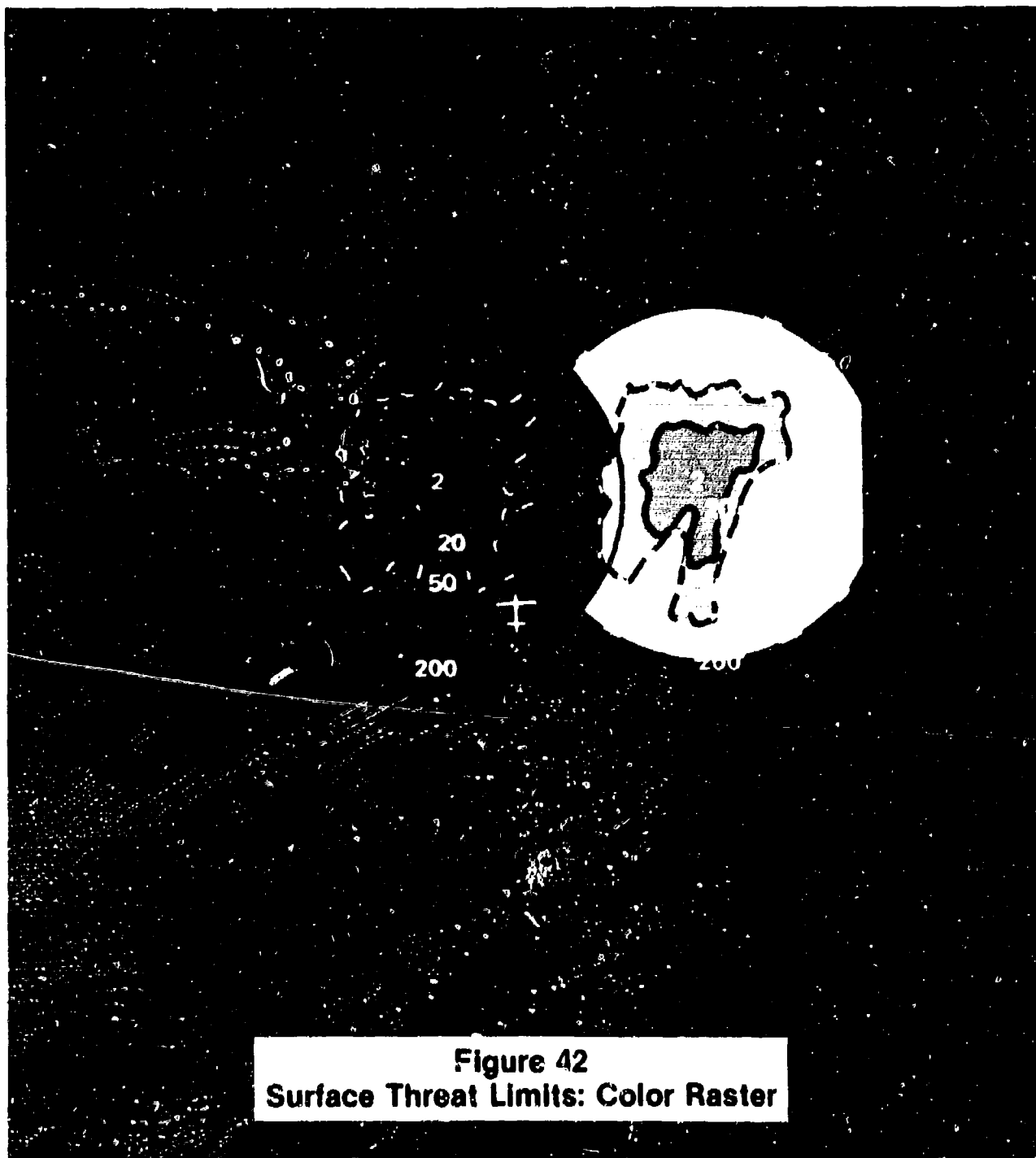
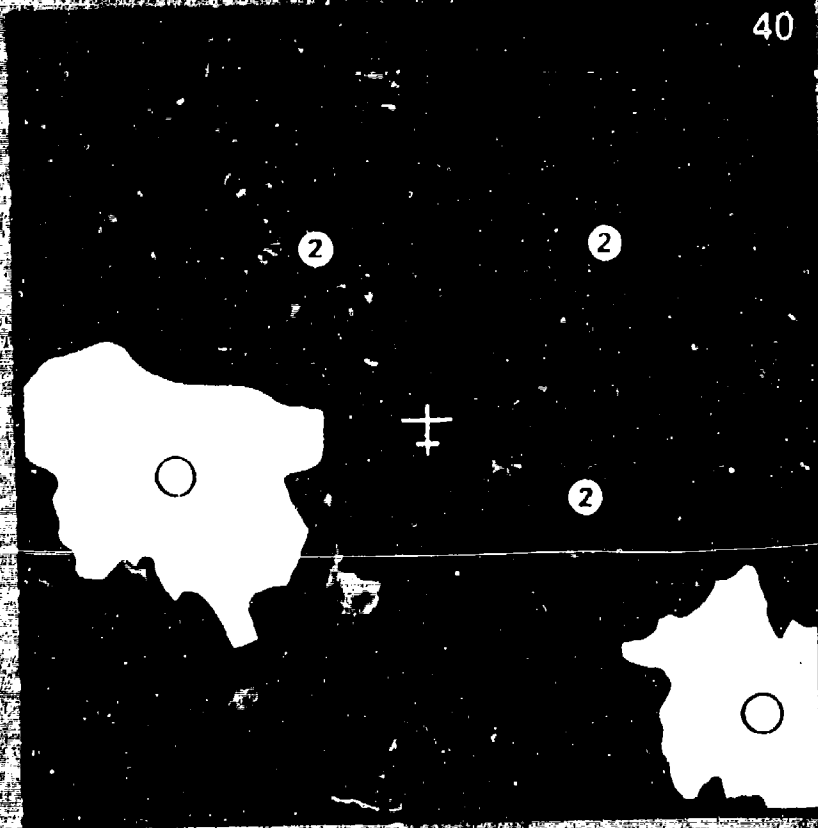


Figure 42
Surface Threat Limits: Color Raster

**HIGH RISK AREAS
THREAT MASKING
AND TERRAIN CLEARANCE
NOT AVAILABLE**



CLEAR AREA - "SAFE TUNNELS"

**Figure 43
Threat High Risk Areas: Color Raster**



Figure 44
Threat Envelope with Graphic and Terrain Data:
Color Raster

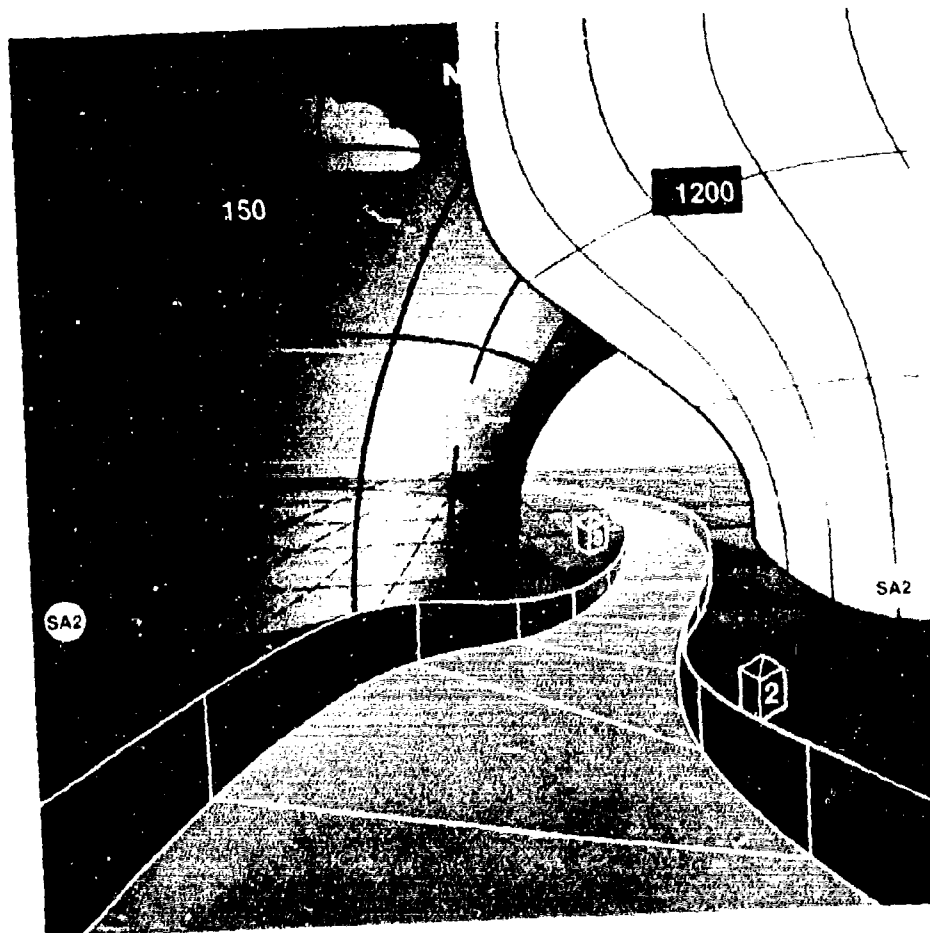
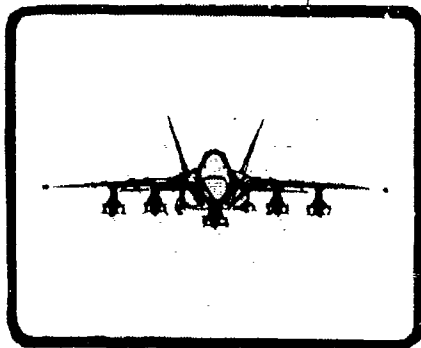


Figure 45
Primary Flight and Tactical Situation Data: Color
Raster

4. STORES STATUS DISPLAYS



Many factors are considered in the stores status displays. A key one is the large number of stores and the very close similarity between many types of stores. This factor dictates eventual use of alphanumerics to supplement the pictorial formats. Other considerations are weapon states and the non-munition type stores -- pods, fuel tanks, etc.

Fundamental weapon states are illustrated in Figure 46. They indicate the steps that must be taken to prepare and launch a weapon. The nominal situation has the weapon onboard the aircraft, initially powered if necessary, and waiting to be selected. After selection there is a finite delay, depending upon

the weapon type, before the weapon is ready for the next step. The master arm switch is assumed on since no weapon delivery can occur when it is off.

After the weapon has been selected and is ready, certain weapons, such as the Maverick, require an uncaging step. The weapon's protective nose dome is blown, and its sensor operation is initiated. Imaging infrared (IIR) Mavericks require a thermal detector to be cooled to a very cold operating temperature. After completing this step the weapon is in an active state and the pilot's attention switches from the stores display to the sensor display. Target acquisition, designation and weapon release steps are accomplished using the sensor display. The last step is weapon release.

4.1 STORES DISPLAYS: MONOCHROME

The primary weapon states -- nominal (or powered), ready, and release--are indicated in the lower half of the format in Figure 47. (No active state is shown in this Figure because the weapons shown are "dumb bombs" and have no active state.) Weapons in the nominal or powered state are also indicated. In this example several conditions of the weapons are shown pictorially including locked, unlocked, hung, and failed. The "master arm" is shown as "ON" using one possible configuration, or symbology. If the master arm switch was off, the display would delete the armed symbol or "SAFE" would replace "ARM."

In Figure 48 the ready, or active, state is shown for a set of Sidewinder and Sparrow air-to-air missiles and four Maverick air-to-ground missiles. Two Mavericks have been selected and are in the active stage. The selected weapons are displayed both oversized and with the annotation "RDY." Such redundant coding accommodates those situations where one coding method may become ineffective. For example, if only one Maverick remained no size comparison could be made and therefore the "RDY" annotation and status indication are the prime weapon state cues. The active state symbol is coordinated with the weapon type. When in active state the Maverick has a TV or FLIR image available. The active state symbol represents the video display showing the target and a designation cursor. For the Sidewinder

WEAPON STATES

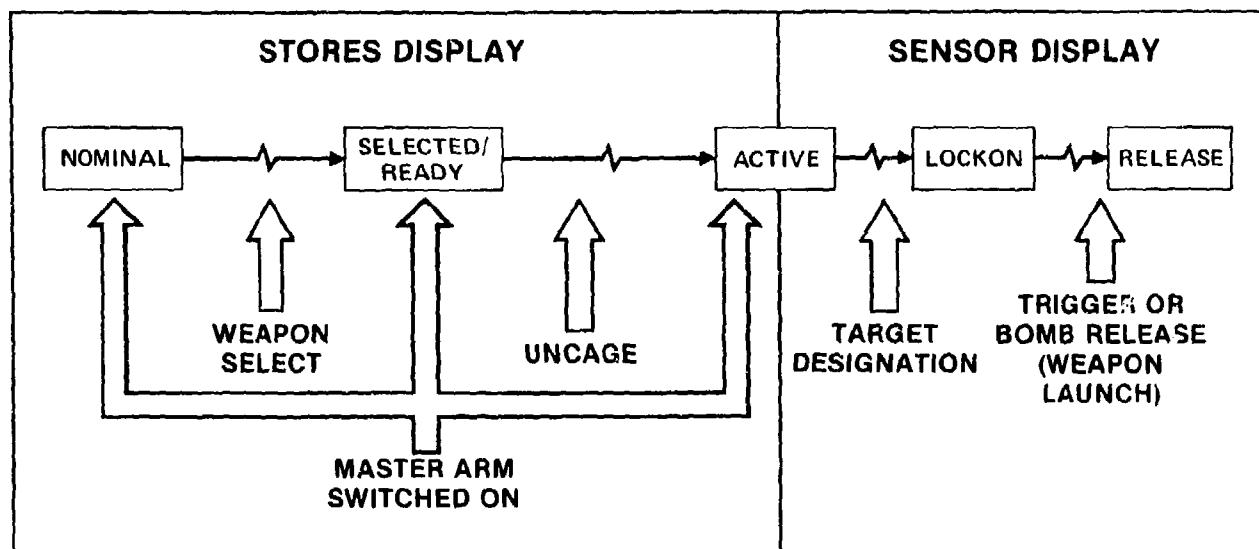


Figure 46
Weapon Release Sequence

GP03 0840 28

NOMINAL (POWERED) STATE

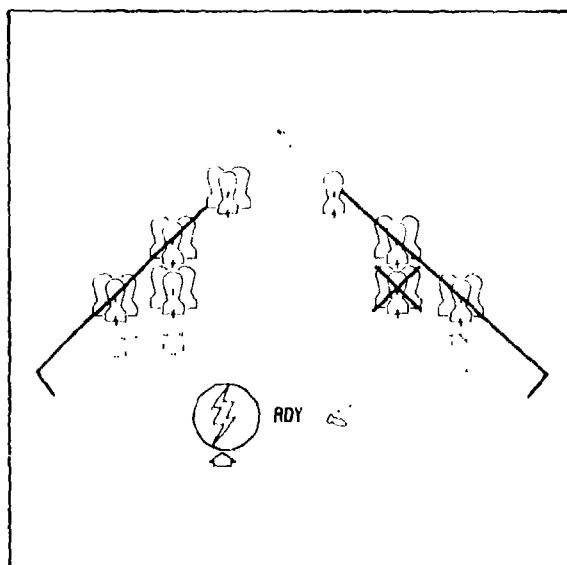


Figure 47
Weapon Status

STORES DISPLAY

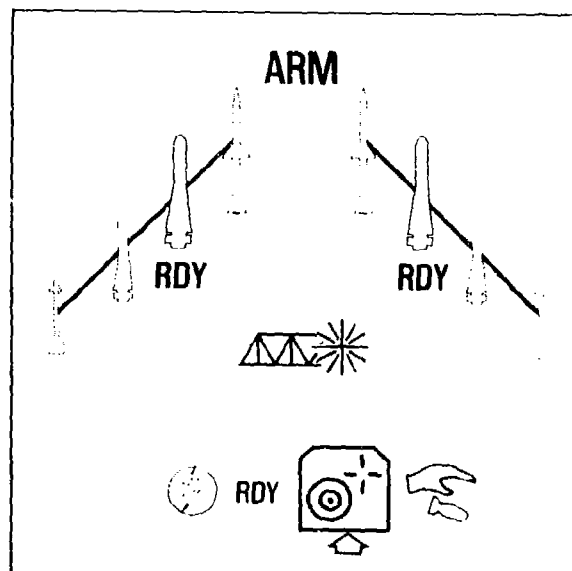


Figure 48
Ready/Active State

the active state symbol would be a head with a set of earphones and sound waves representing the audio tone given by the Sidewinder when it is ready for launch. The weapon delivery program selected is also indicated. In this case, it is a program used to attack a bridge. The symbology for the bridge is used in lieu of the current procedure which designates the programs numerically. Five different programs can be programmed in the F/A-18 aircraft. The next step in the stores management procedure is to release the weapon. This is done with the sensor display rather than the stores display. Figure 48 also shows an alternative way of displaying the master arm control status.

Another factor to be considered in developing the store status display is the procedure and format to be used when developing the delivery programs. Figures 49 and 50 illustrate a format to do this. In these examples the target is a tank or armored vehicle. The delivery mode is selected from 1 of 4 choices -- automatic, terrain clearance avoidance (TCA), continuously computed impact point (CCIP), or manual. Both electrical and mechanical fuzing options can be selected. For mechanical these options are nose, tail, both or none (defuze). The electrical options are proximity (variable time fuzing), contact fuzing (instantaneous detonation), and two values of delay. An advantage of pictorial formats is they provide a more realistic impression of what is actually happening with the fuzing. The last parameter to be selected on this format is the weapon drag. The two options are slick or high drag.

AIR-TO-GROUND PROGRAM ARMING SELECTIONS

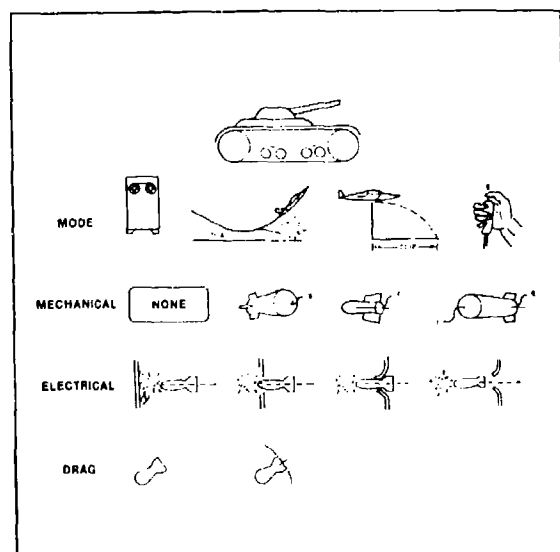


Figure 49
Weapon Programming Functions

AIR-TO-GROUND PROGRAM RELEASE SELECTIONS

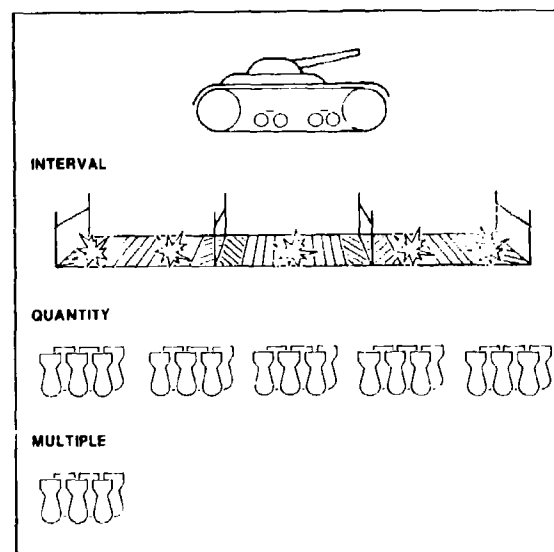


Figure 50
Weapon Release Options

In Figure 50, additional parameters such as weapons interval, quantity and multiple are selected. They indicate how many weapons will be delivered and how far apart the burst pattern will be spread on the target area. The values indicated are for illustration only. Although it is not practical to deliver that many weapons against a single tank, that particular program might be used if the target were a column of tanks. It would be up to the pilot to recognize whether the target is a column of tanks or a single tank and make the appropriate selections.

4.2 STORES DISPLAYS: COLOR STROKE

In Figure 51, as in Figure 47, no active state is shown because the weapons shown are dumb and as such have no active state. They simply go from nominal to ready and then to release. The white line shows the planform of the wing. The orange indicates powered state and the yellow cross is a precautionary indication that these weapons have failed, i.e., they cannot be delivered as desired due to a failure in the weapons themselves but they can be defuzed (they are not hung). The scaffolding with the hangman's noose is used to indicate a hung weapon.

In Figure 52 the status of the weapons is color-coded to agree with the weapon status, in this case active. There are actually two kinds of ready in this example. The typical ready state, reached after weapon selection and power-up is completed, indicates a readiness to proceed to the next step and is color-coded yellow. The green-coded Maverick is in the "second ready state" which corresponds to the active state. All preliminary launch steps have been accomplished and the next step is launch. After the green-coded weapon is launched, the yellow-coded weapon is automatically sequenced to be launched. Since the aircraft is in an air-to-surface mode, the air-to-air weapons, (Sparrows and Sidewinders) are in white. If the pilot should change mode, or select one of those weapons, they would then be indicated with the yellow/green coding, and the air-to-surface weapons would turn white.

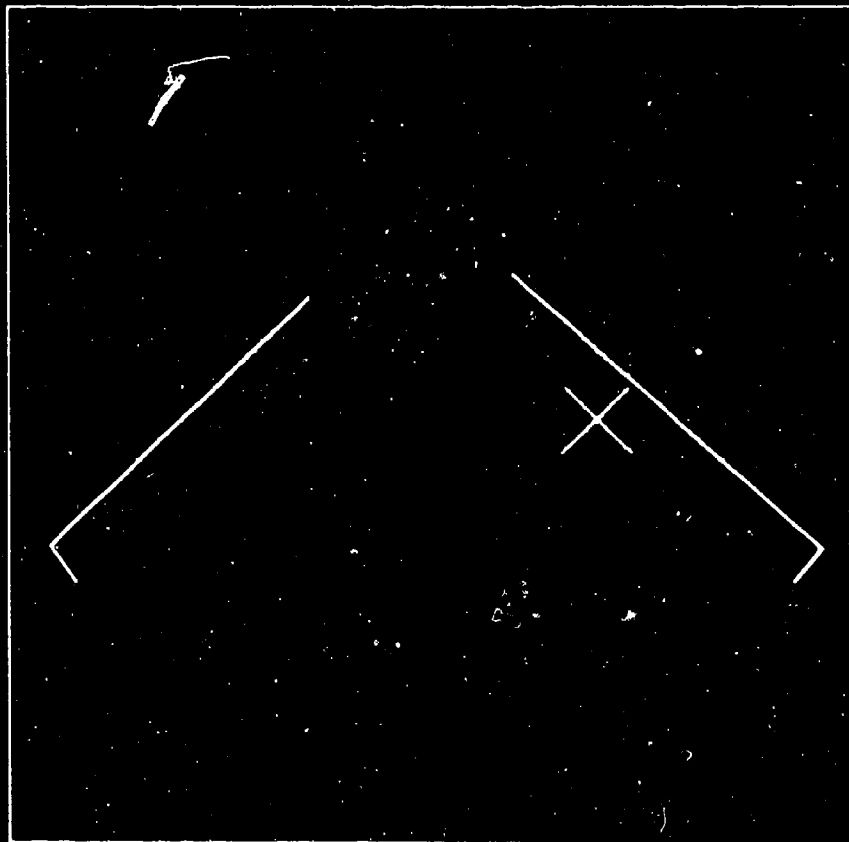
Color coding in Figures 53 and 54 is set simply to draw attention to various parts of the weapons being addressed by either the fuzing or the delivery and for good symbology contrast. The tank is green to provide a realistic relationship to an actual tank. The bomb bursts in Figure 54 are orange instead of the more conventional red and yellow to prevent confusion with red-coded emergency action items.

4.3 STORES DISPLAYS: COLOR RASTER

Figures 55, 56, 57 and 58 illustrate the color raster version of the stores situation displays. They use the same color coding as previously described. The raster fill capability has been used to make the various symbols in the display solid colors. This capability permits different backgrounds to be used and colors to be changed so that symbology stands out or is more predominant.

NOMINAL (POWERED) STATE

- QUANTITY
- TYPES



- CONDITIONS
- MASTER ARM

Figure 51
Weapon Status: Color Stroke

STORES DISPLAY

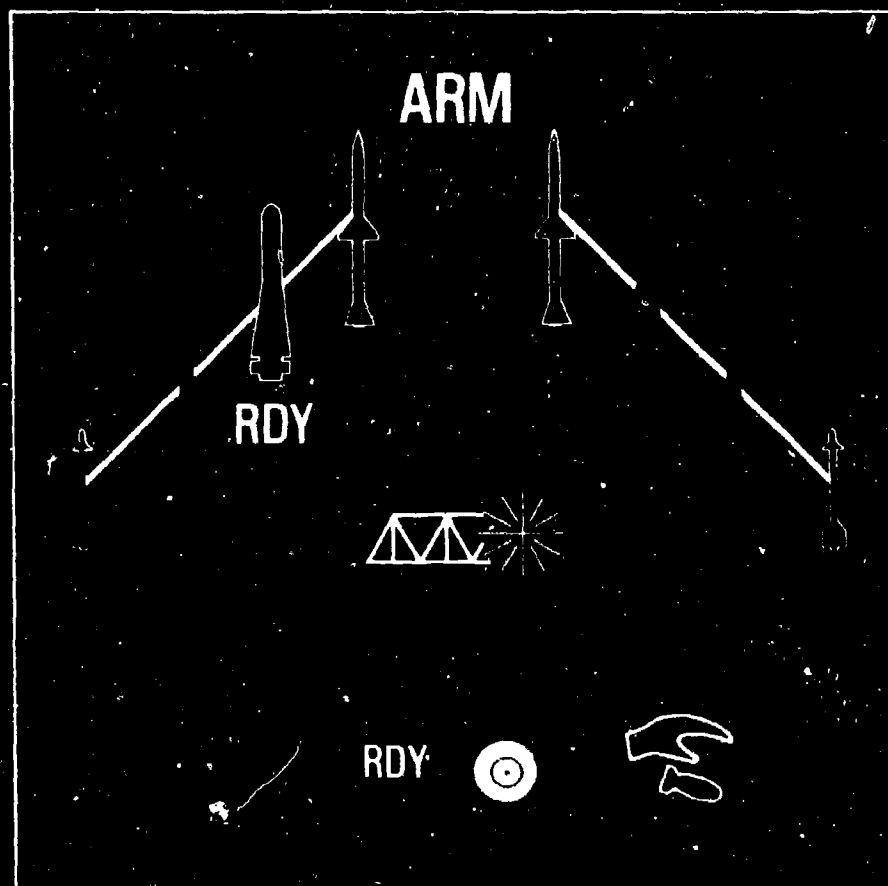


Figure 52
Ready/Active State: Color Stroke

AIR-TO-GROUND PROGRAM ARMING SELECTIONS

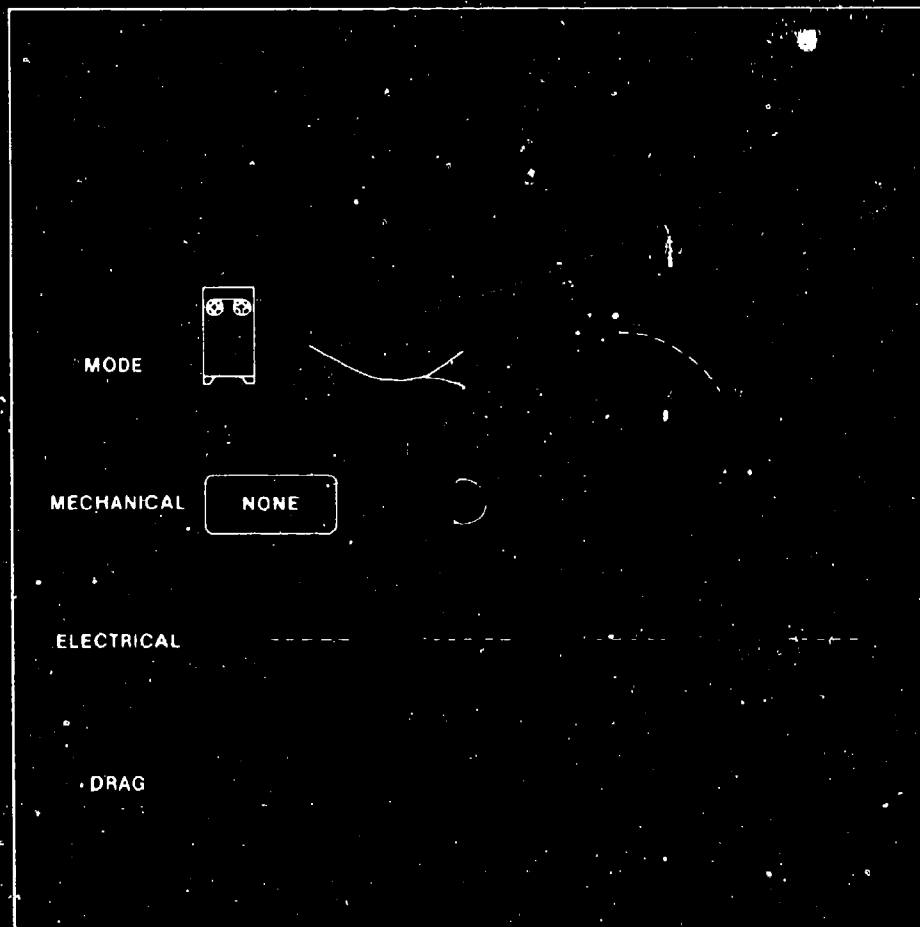


Figure 53
Weapon Programming Functions: Color Stroke

P01 DR TO 13A

AIR-TO-GROUND PROGRAM RELEASE SELECTIONS

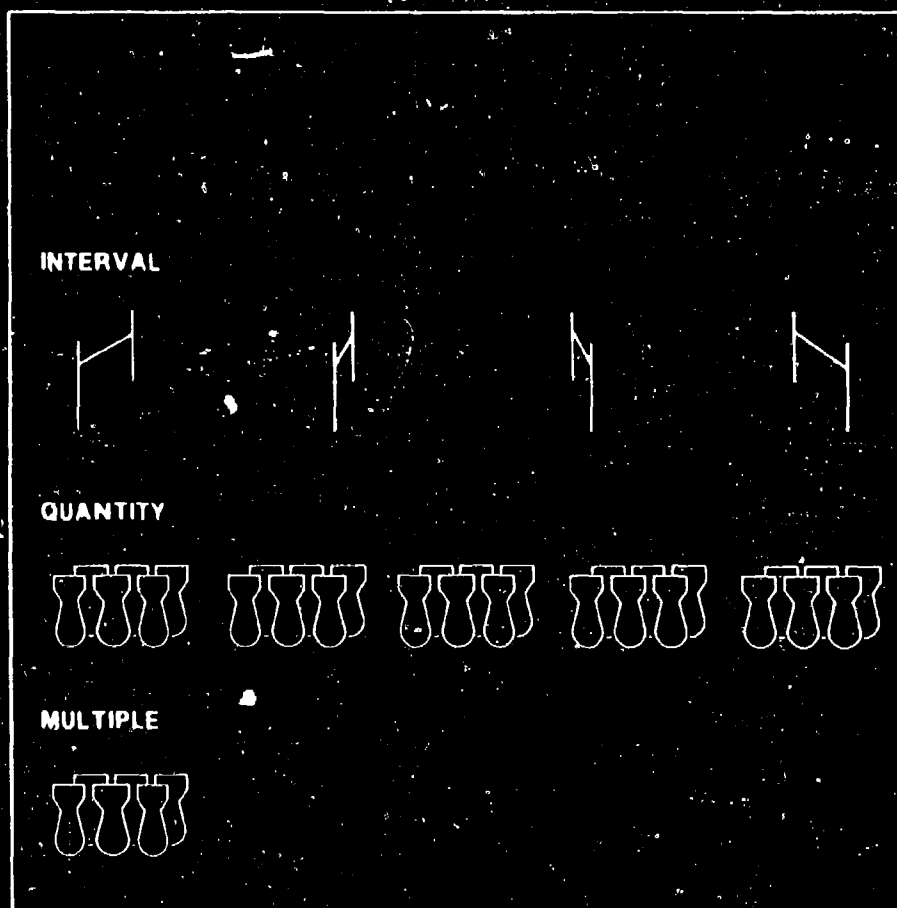


Figure 54
Weapon Release Options: Color Stroke

NOMINAL (POWERED) STATE

• QUANTITY

• TYPES

• CONDITIONS

• MASTER
ARM

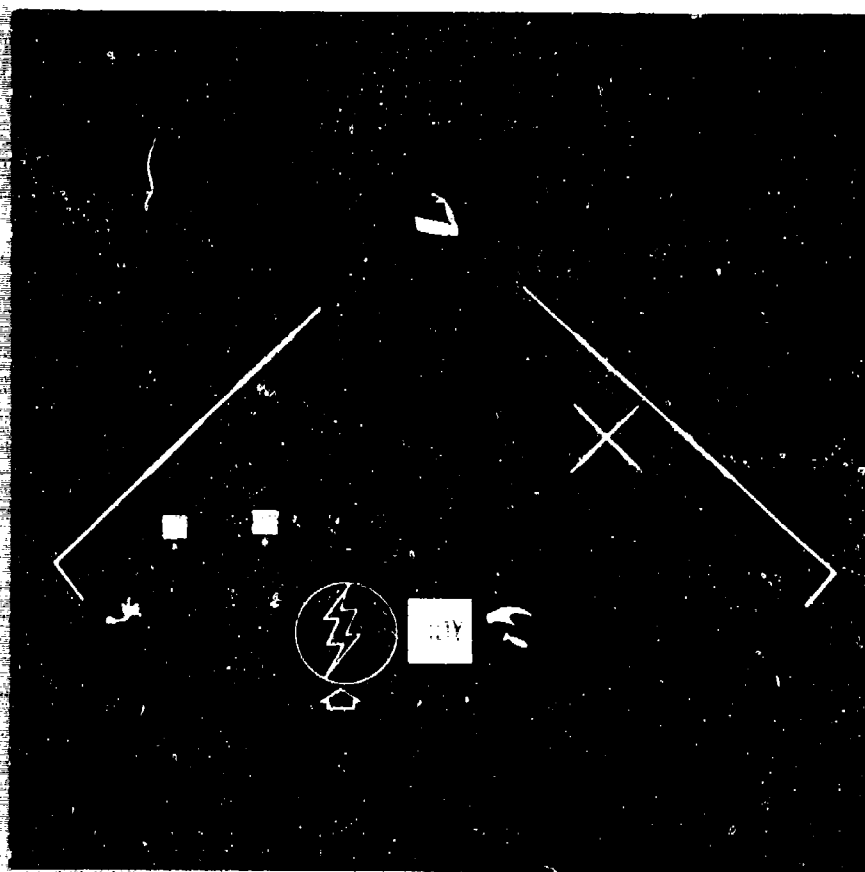


Figure 55
Weapon Status: Color Raster

SP91-0570-300

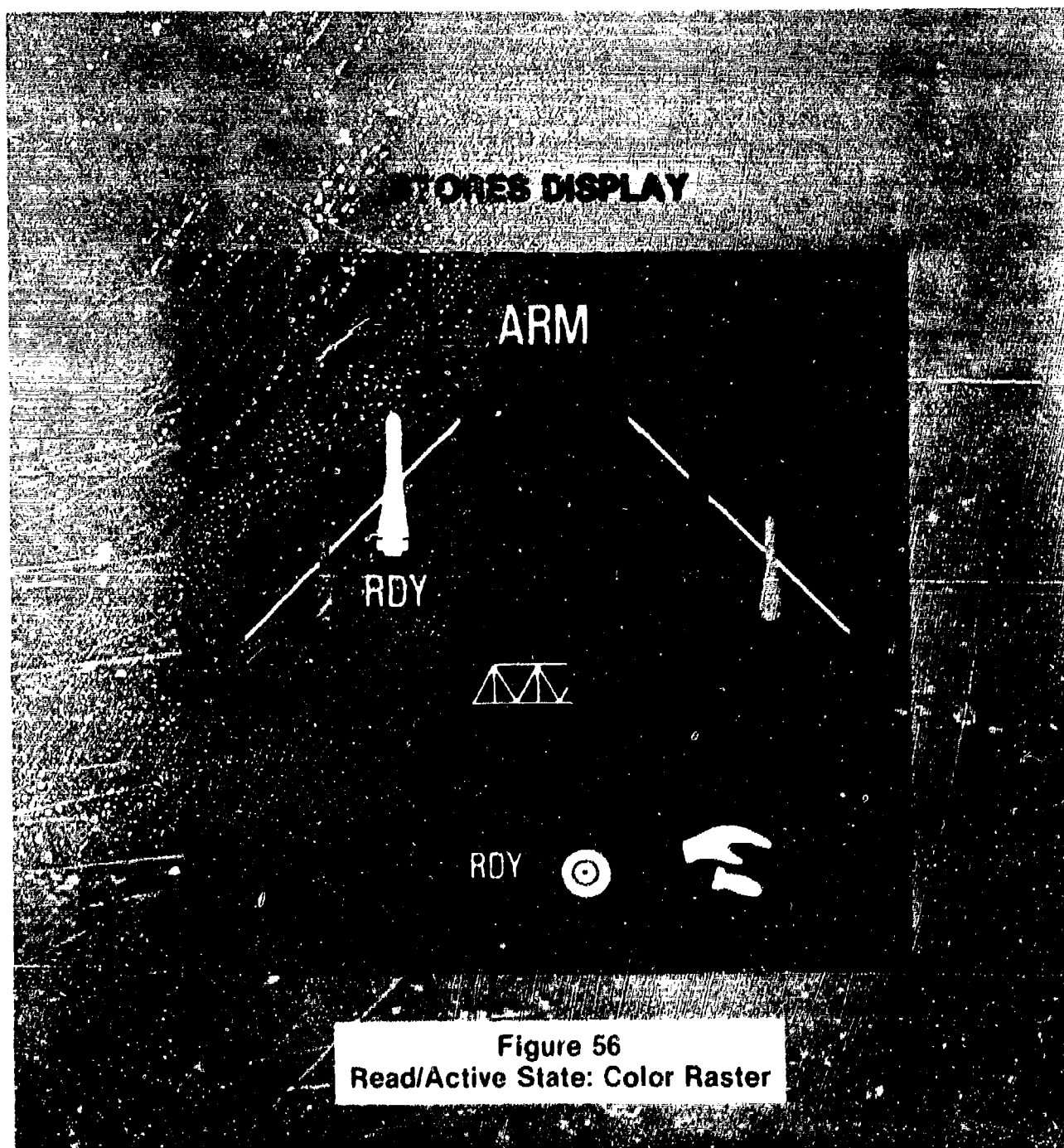
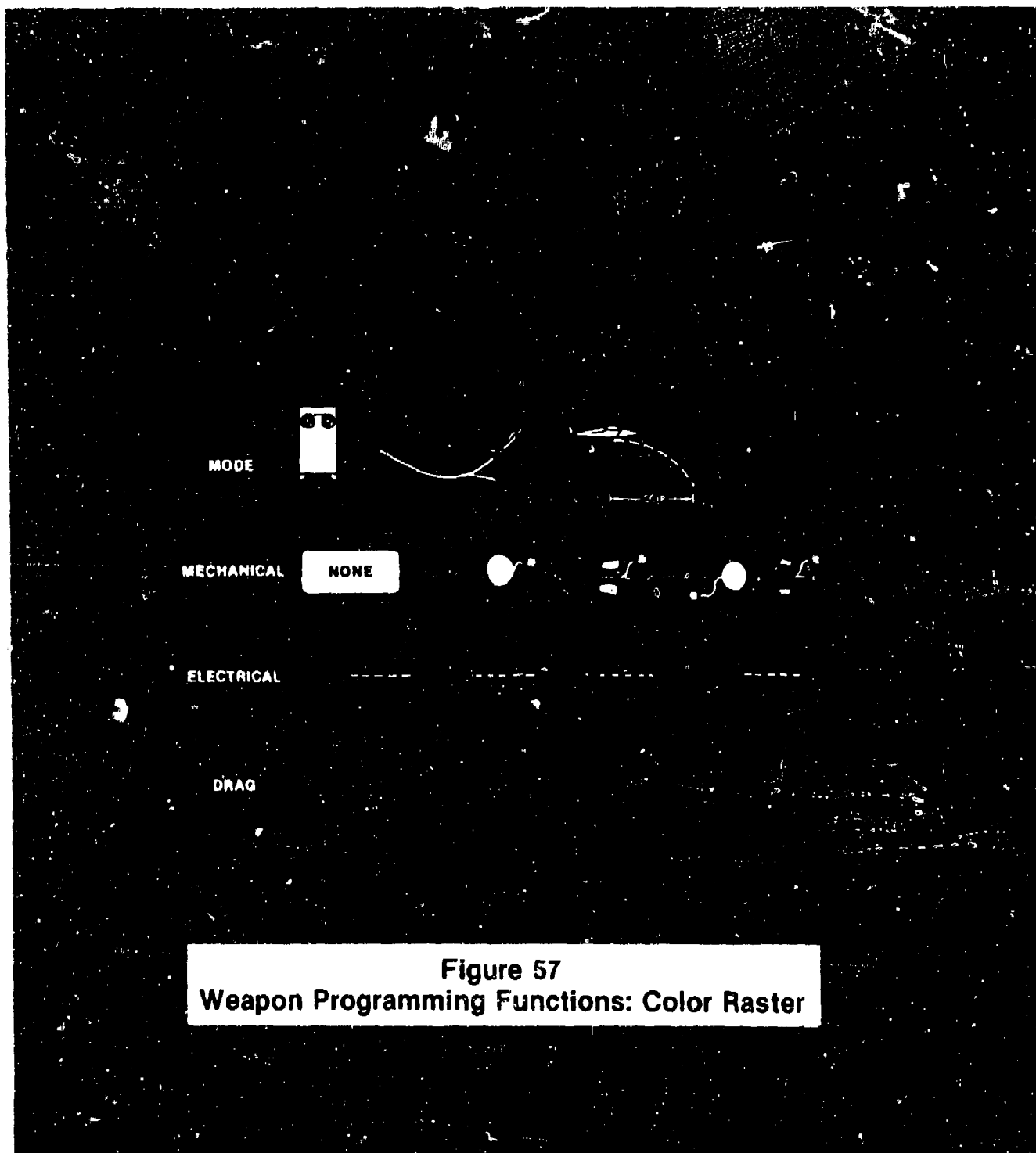


Figure 56
Read/Active State: Color Raster



AIR-TO-GROUND PROGRAM RELEASE SELECTIONS

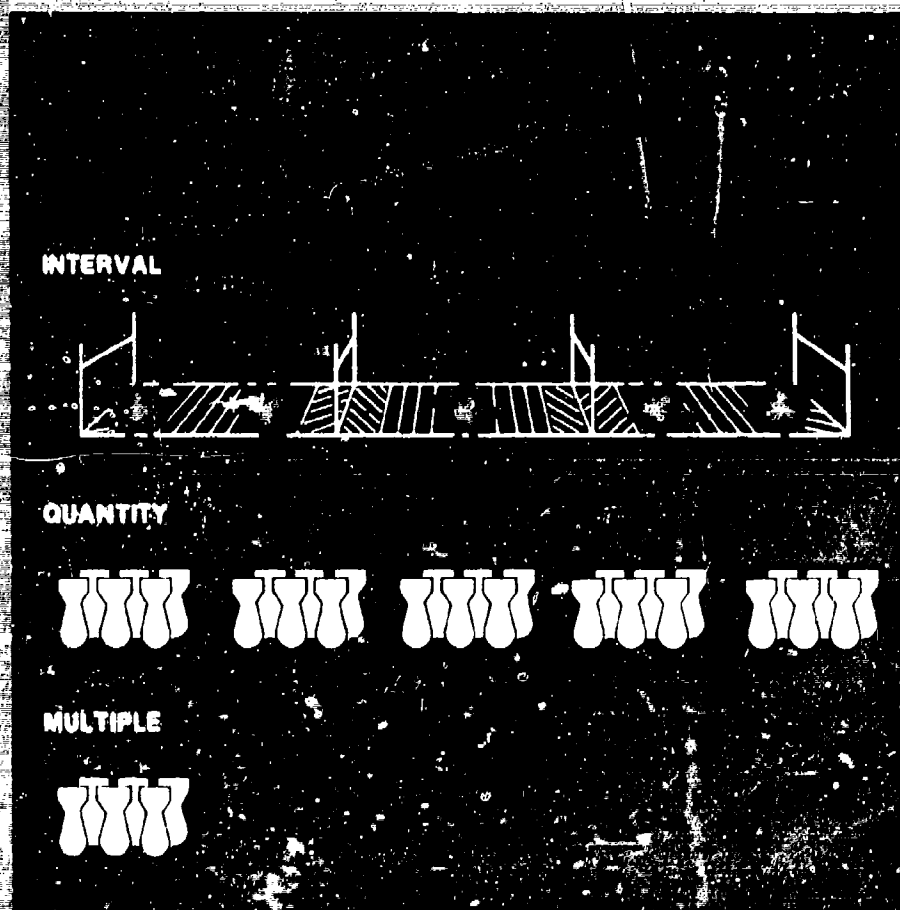
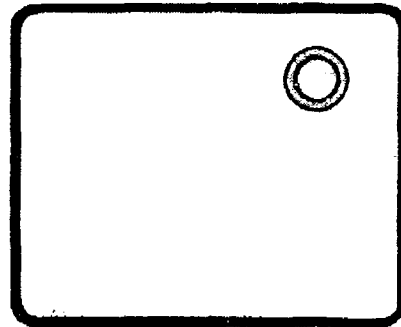
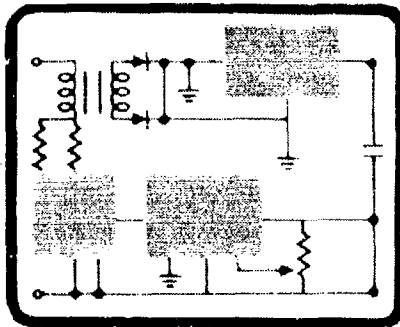


Figure 58
Weapon Release Options: Color Raster

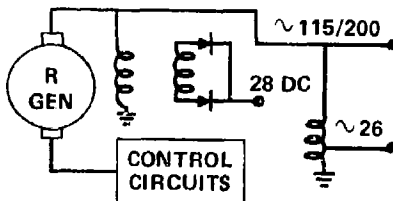
GP01-0870-346

5. SYSTEMS/EMERGENCY PROCEDURES DISPLAYS

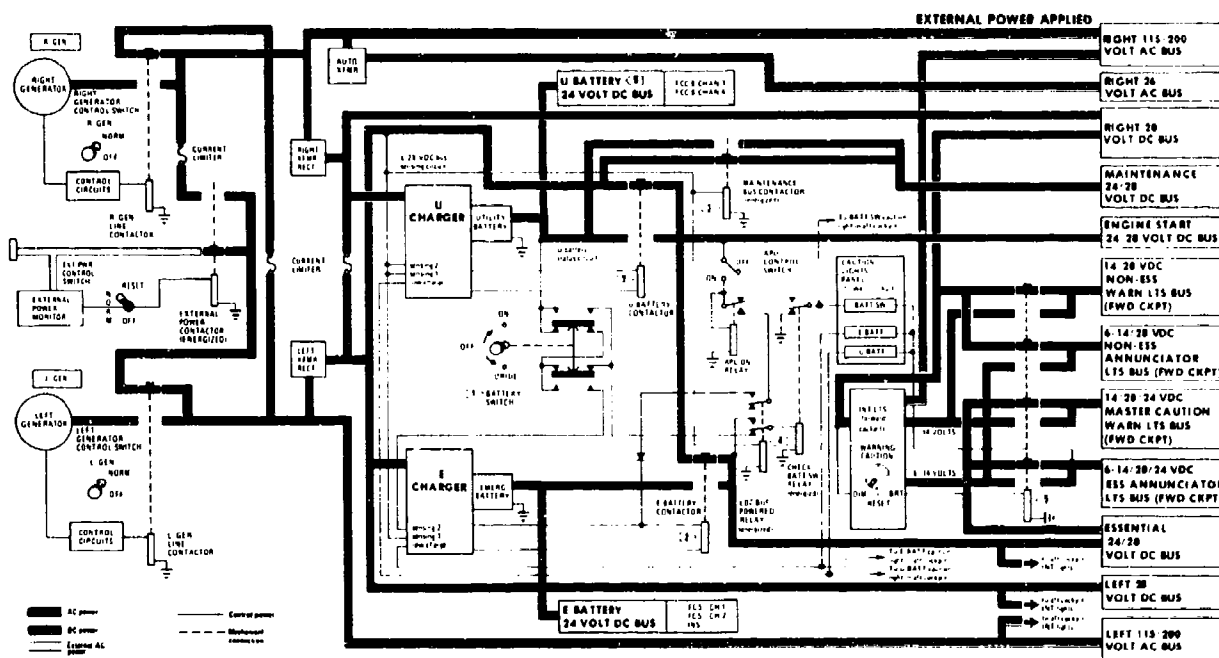


The systems status displays are intertwined with the emergency procedures displays because one follows from the other. It is a natural way to present the data. An emergency situation is really an extension of systems status, gone beyond normal or reasonable operation. In this section the electrical, hydraulic, and fuel systems are covered. Also, the engine displays are covered as a system since for all practical purposes they function very much like a system. When developing systems status displays a strong temptation to present too much information to the pilot must be overcome. Pictorial formats can impart a great deal of information in a short period of time. It is important to remember that the information should be screened as much as possible when integrating the formats into the total cockpit design. The displayed information should be reduced to only the essentials required or desired by the pilot.

5.1 ELECTRICAL SYSTEM



A typical aircraft electrical system schematic is shown in Figure 59. It is very complex, but nevertheless this represents only a fraction of the schematic since it could be further defined to show what systems are serviced by each bus. This is considerably more detailed than what the pilot needs or wants to know about the electrical system. He is interested in things that immediately affect him: does he or does he not have adequate power; is he operating on reduced power; has he lost one or two generators; is he operating on a stand-by or emergency generator; is he operating on a stand-by battery system; how much time does he have left on a battery; what is the status



GF01 0870 101

Figure 59
Strike/Fighter Aircraft Electrical System

of the standby; is the standby overloaded; and have systems been lost due to the electrical failure? Questions like this must be answered. The pilot is not an engineer trying to analyze the system.

5.1.1 Electrical Formats: Monochrome

Figure 60 is a schematic of the electrical system that is much abbreviated from Figure 59. Even more abbreviated displays using indicator lights, and a simple symbol for electrical system might also be used for many situations. However this more detailed display is presented as an option available to the pilot when he wants to know more detail about the electrical system status than simply "go" or "no-go." In this illustration the system is assumed to be operating in a normal condition. It is a dual generator system (BAT CHG) (L GEN, R GEN) with left and right AC buses (L AC, R AC), and left and right transformer-rectifiers (L XFMR RECT, R XFMR RECT) supplying DC buses (L DC, R DC). The backup batteries (EMER, UTIL) are continuously charged (BAT CHG) while the system is in normal operation.

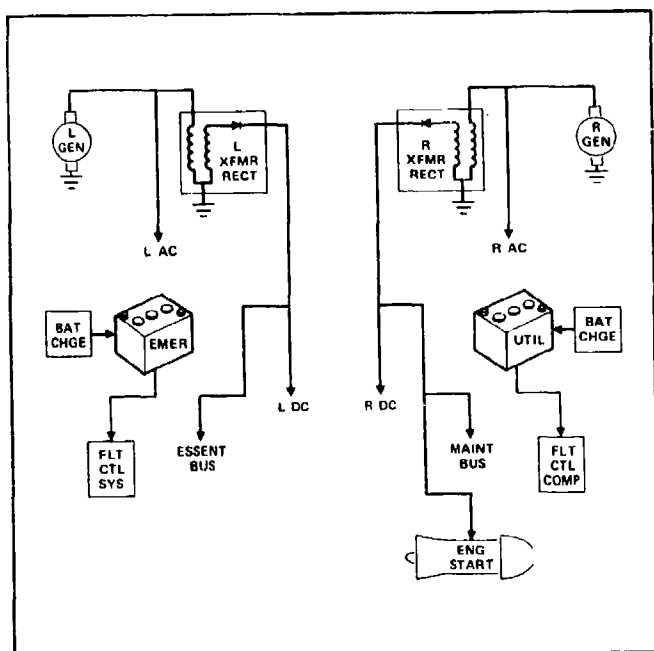


Figure 60
Normal Electrical Status

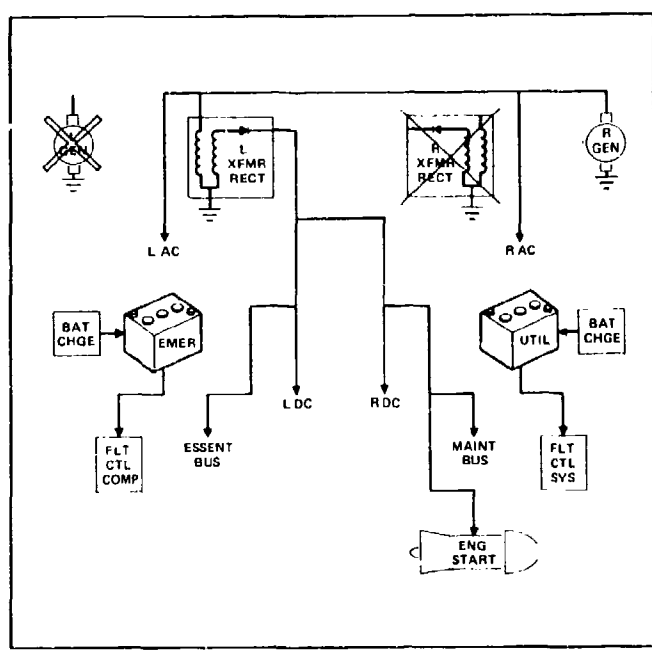


Figure 61
Partially Failed Electrical System

In Figure 61 a situation is shown where the left generator (L GEN) and the right transformer-rectifier (R XFMR RECT) have failed. The solid cross overlaying the transformer-rectifier indicates a permanent failure. The open cross overlaying the left generator symbol indicates a possible intermittent failure, or at least at this stage that the generator has failed once. The system continues to operate as efficiently as the normal system, the only difference being that a level of redundancy and reliability has been removed. It could be argued that this need not even be shown to the pilot since there is nothing he can do about it. The transfers are made automatically to put both AC buses (L AC, R AC) on the right generator (R GEN), and both DC buses (L DC, R DC) are automatically connected to the left transformer-rectifier. A different system in which transfers are not automatic would mandate that this information be displayed to the pilot so that he knows what buses, or what systems, he has lost and what action is needed to remedy the situation.

After this failure an emergency situation is declared by the system, as shown in Figure 62. Here the cross-hatched border indicates an emergency situation and the corrective action is indicated by the commanded cycling of the left generator (L GEN) OFF switch. (Cross-hatch density would be heavier for emergency formats than for caution formats.) The display shows not only the action to be taken but in what part of the cockpit the pilot should look for the control. In this display the generator is still assumed to be an intermittent failure since the switch has not been cycled yet. In Figure 63, the cycling has taken place and the generator remains failed. The open cross has been replaced by a solid cross over the generator symbol. The commands to the pilot are 1) turn the left generator to off; and 2) proceed to land as soon as reasonably possible.

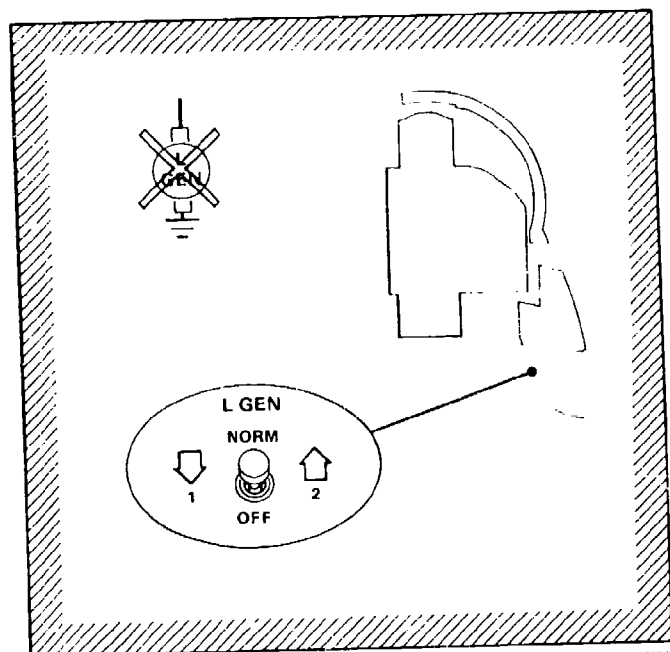


Figure 62
Emergency Corrective Action

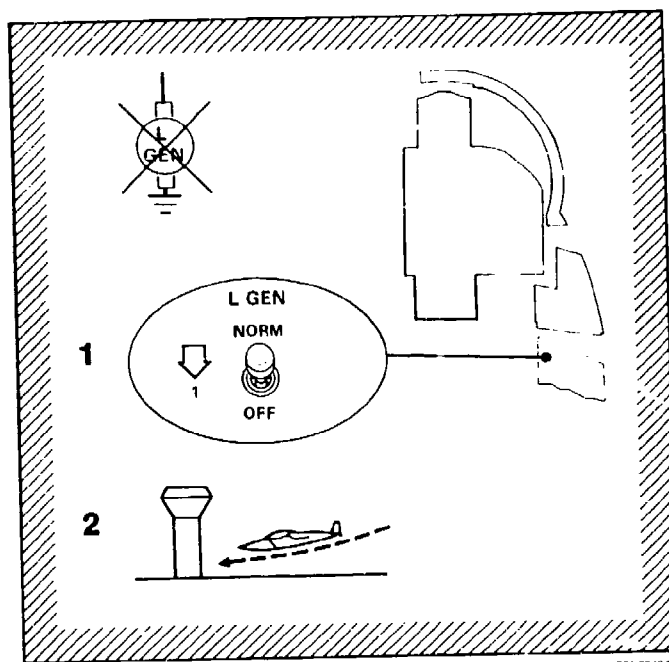
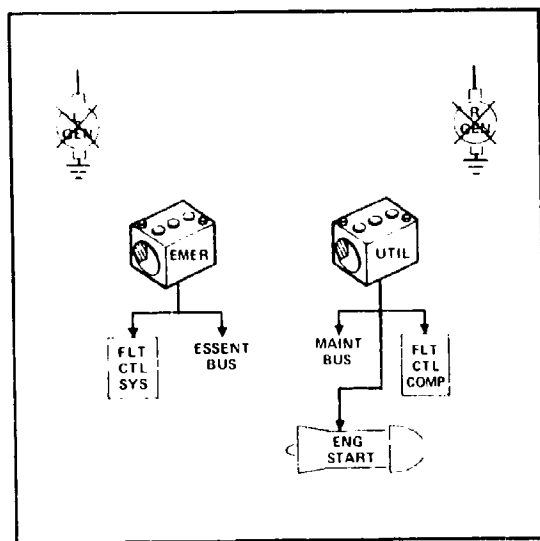


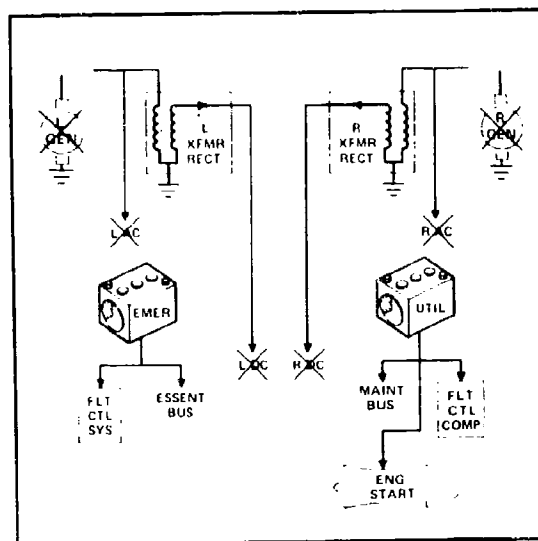
Figure 63
Completely Failed Generator

Figure 64 shows the systems status when both generators fail. Both transformer-rectifier pairs are ineffective since there is no power to them, and the system is operating on batteries. An alternate format is shown in Figure 64 (b) where the additional data of the lost buses is shown. Figure 64 (a) is the preferred format as it operates more on a management by exception principle. It shows the electrical power which is available rather than cluttering the display with unnecessary information about everything that has been lost. This display is shown as a status display although it would immediately change to an emergency situation display and have the crosshatched borders indicating emergency.

Figure 65 shows the corrective action to be taken by the pilot. It is very similar to Figure 62. The primary difference is that two generators have failed, so both generator symbols are shown along with corrective action commanding cycling of both generator switches. Both generators have been determined to be in permanent failure. Therefore, the crosses are closed rather than open. Open crosses would denote intermittent or temporary failure.



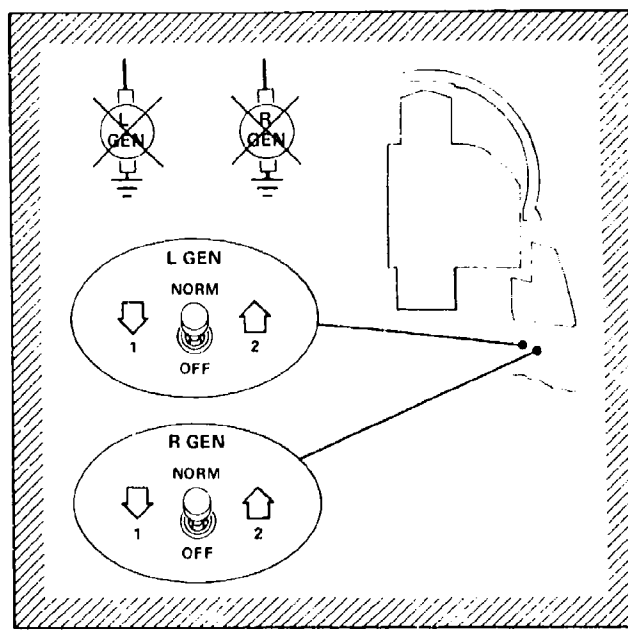
a) BASIC FORMAT



b) ALTERNATE FORMAT

GP01 0870 103

Figure 64
Dual Generator Failure



GP01 0870 09

Figure 65
Immediate Action Failures
for Generator

If the failure is permanent, the corrective actions indicated in Figure 66 will be displayed. This is also an emergency situation and both generators are shown with permanent failures indicated by a solid cross over each. Additional information items are provided. First the pilot should minimize the electrical load, trim adjustments, and UHF transmissions to preserve the batteries. Any stores on board can be jettisoned if necessary. Fuel transfer from the wing tanks to the internal tanks has been lost. And finally, he has an option available by pressing a peripheral button on the display, or if a touch-sensitive display is used, simply by touching the arrow.

The option format is displayed in Figure 67. The failed generators still appear at the top of the display so that the pilot remains aware of the situation, and the optional steps available are indicated. The first step is to set calculated airspeed between 200 and 300 knots. The second step is to pull out the circuit breakers for both channel 1 and channel 2 flight control systems. The display indicates where these switches are in the cockpit. In this example they are on the left hand console. The third and last step reminds the pilot that both channel 1 and channel 2 systems should be re-engaged prior to landing the aircraft.

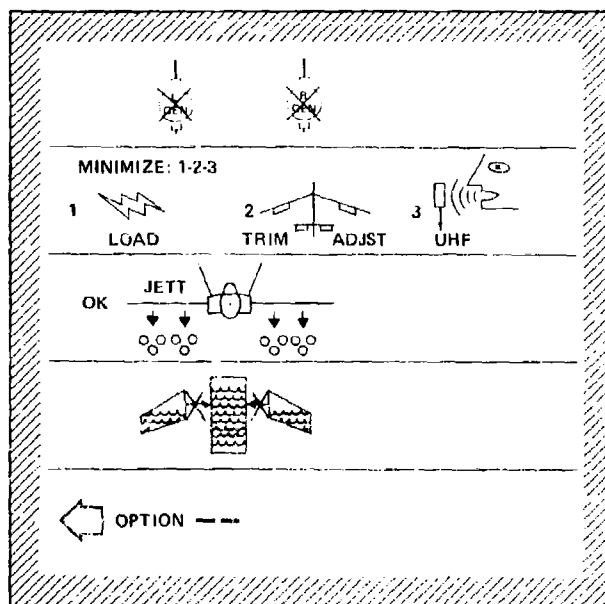


Figure 66
Additional Emergency Actions for Generator Failures

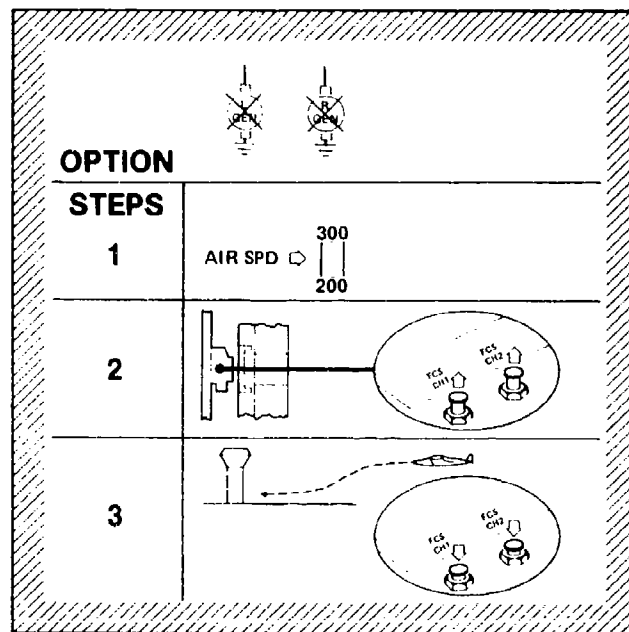


Figure 67
Optional Emergency Steps

5.1.2 Electrical Formats: Color Stroke

This section illustrates how color coding can assist the pilot in interpreting the displays. Figure 68 indicates a dual generator failure in which both generators have a red solid X through them to indicate failure. The standby batteries, both emergency and utility, are orange consistent with the electrical system color coding. The clock face on each battery is red and green. Green indicates the remaining time available on the battery and red completes the face to give it context and understanding. The power buses are white to give good contrast to the background while remaining consistent with the use of white for designating self.

Figure 69 shows the corrective action when both generators fail. The red cross-hatched border indicates the emergency situation requiring immediate action. Red open crosses through the generators indicate an intermittently failed generator. White is used for self-designation of the instrument panel and outlines

the canopy bow to help indicate where the switches are on the panel. White on the switch nomenclature and switch symbol is consistent with previously described color coding. The yellow arrows, oval outlines, and solid lines joining the ovals to the instrument panel all provide good contrast and visibility for these important functions.

Figure 70 shows the color coding associated with the additional actions after both generators have been permanently failed. White is used for contrast purposes and as self-designation for trim, jettison, UHF transmission, and fuel tanks. Blue fill lines for the fuel are aesthetic and realistic to help the pilot recognize the fuel situation. The red crosses through the transfer points indicate the failure of that transfer capability. The option arrow is yellow to indicate continued precautionary action and for contrast with the black background.

The option steps in Figure 71 are the same functions as previously described. The airspeed arrow indicates the commanded value and the orange tape values indicate the range of values available. The green ground is consistent with the green or brown grid used for ground information in the flight and TSD displays. Magenta on the airfield control tower is consistent with color coding used on the tactical situation displays.

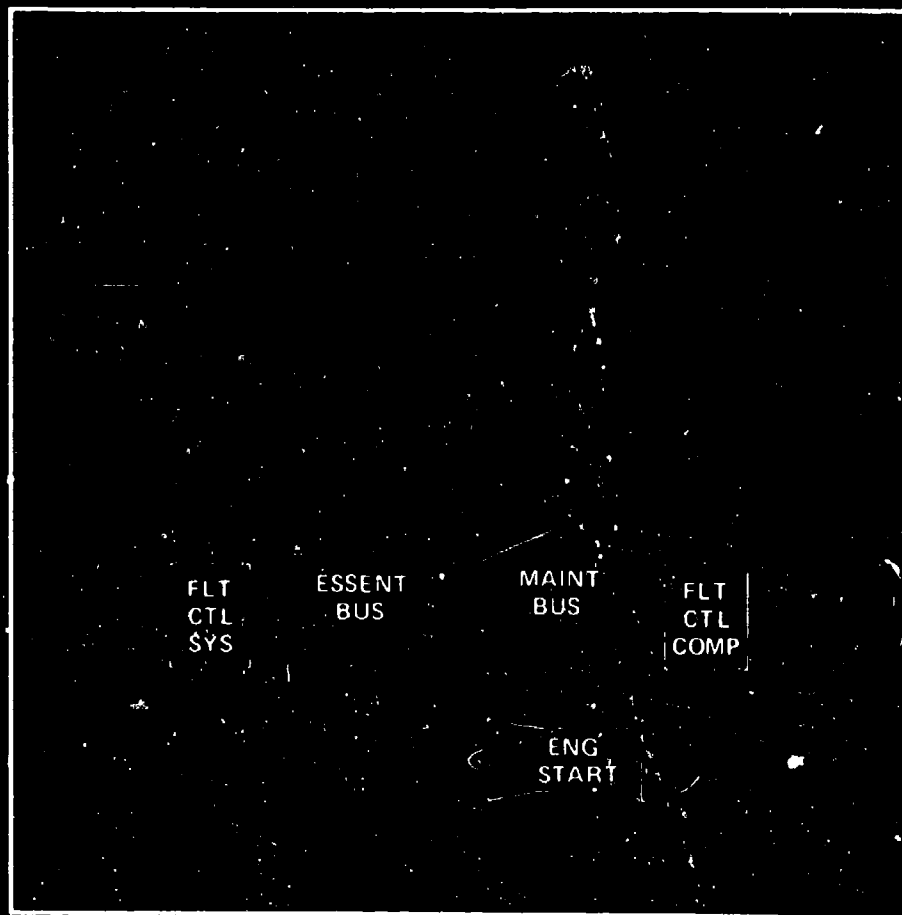
5.1.3 Electrical Formats: Color Raster

Figure 72 indicates the effective use of fill behind the generators and within the batteries in the bus description boxes to highlight these features with a minimum of processing requirements and yet retaining full impact of the color raster graphics capability. The clock on the face of the battery is dynamic. It moves towards zero at 12 o'clock, with the face all red when the time available on the batteries has decreased to zero.

Figure 73 shows the emergency procedures to be followed in recycling the failed generators. Color raster is used to fill the surrounds of the different instructions and the failed generators and highlight them for immediate recognition by the pilot.

Figure 74 shows the use of different colored backgrounds in the raster to help accentuate the different information items and various steps to compensate for the generator failures. Fuel levels in the fuel tanks show available fuel as blue and empty portions of the tanks as yellow. This coding scheme is consistent with fuel displays to be discussed later.

Figure 75 also demonstrates the use of various color background fills to highlight specific areas of the display and coordinate, or separate, different action items and information.



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Figure 68
Dual Generator Failure: Color Stroke

L GEN

NORM



OFF

R GEN

NORM



OFF

Figure 69
Immediate Action for Generator Failures:
Color Stroke




Figure 70
Additional Emergency Actions for Generator
Failures: Color Stroke



Figure 71
Optional Emergency Steps: Color Stroke

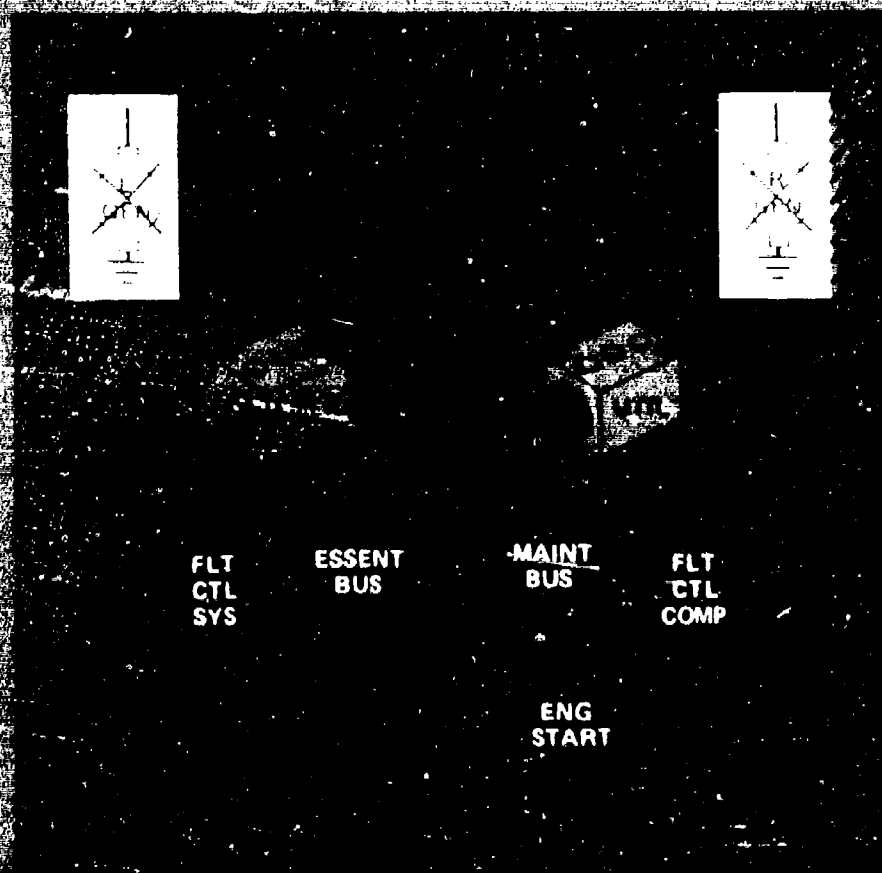


Figure 72
Dual Generator Failure: Color Raster

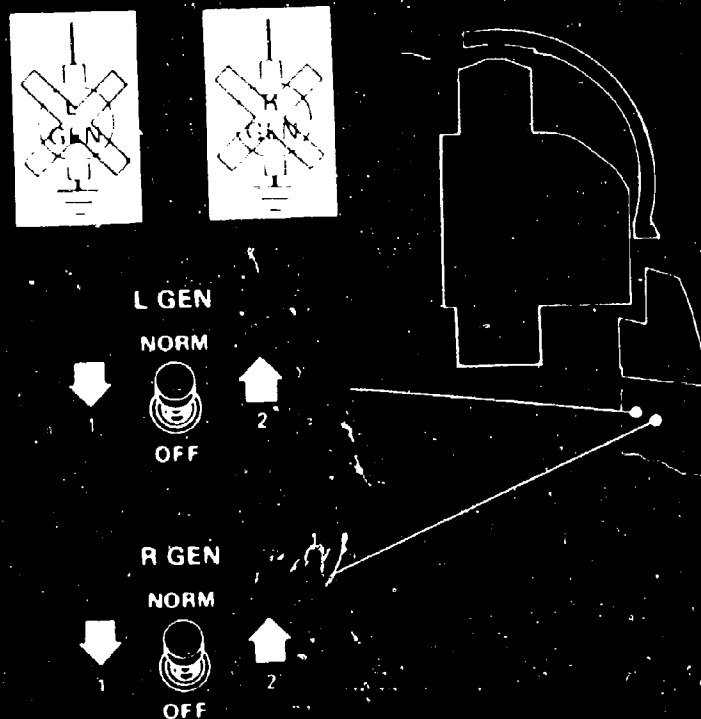


Figure 73
Immediate Action for Generator Failures:
Color Raster

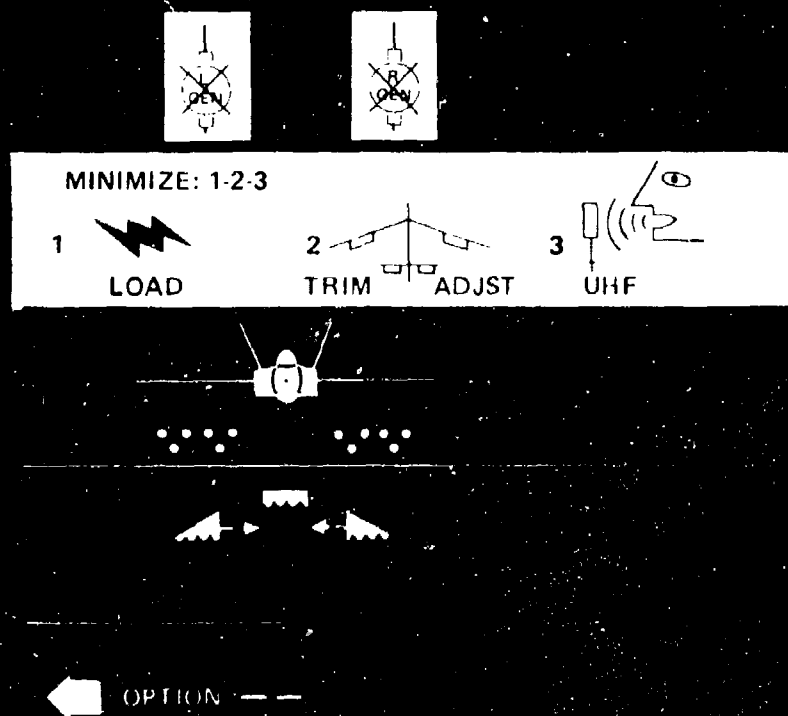


Figure 74
Additional Emergency Actions for Generator
Failures: Color Raster

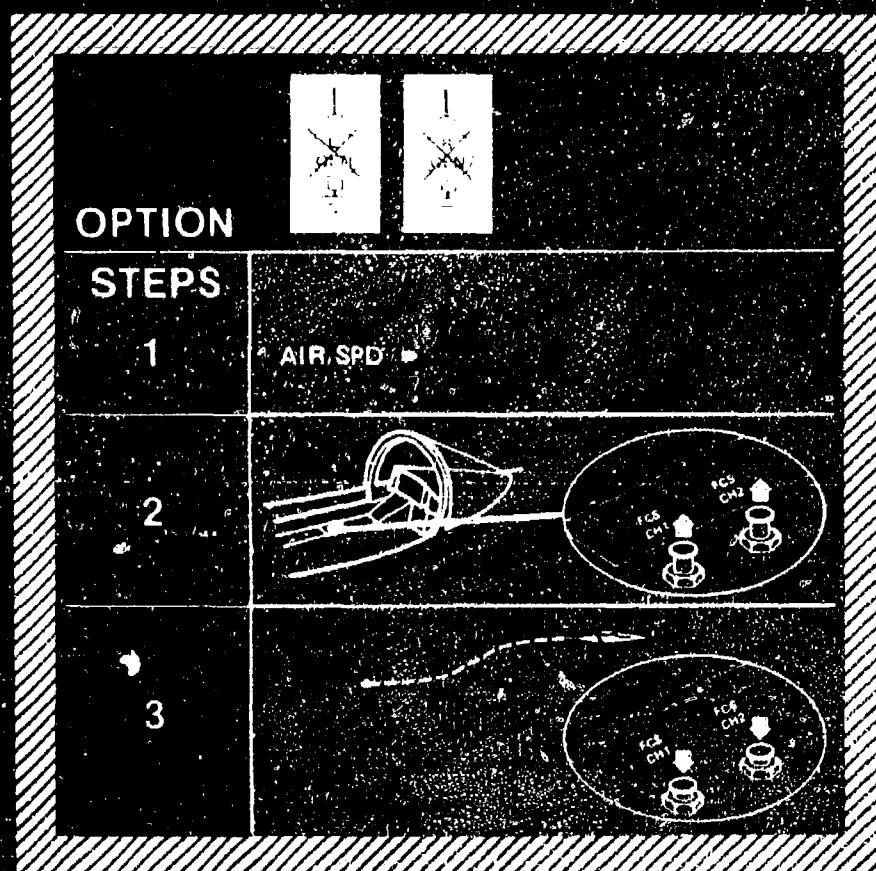
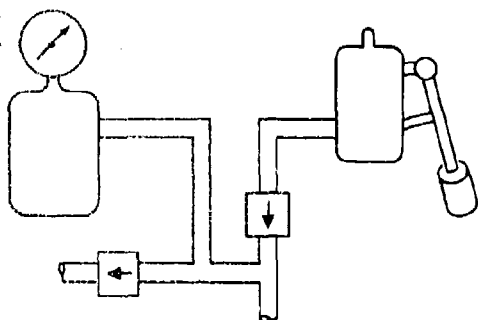


Figure 75
Optional Emergency Steps: Color Raster

5.2 HYDRAULIC SYSTEM



The schematic for the hydraulic system, Figure 76, is simpler than for the electrical system. This is a system with dual redundant circuits. It is still a complex schematic and provides much more information than the pilot really needs to know about the hydraulic system. He is not a hydraulic engineer and does not wish to repair the system. There is not much he can do, except for certain emergency procedures which are illustrated in the formats showing him specifically which components to use for each failure.

5.2.1 Hydraulic Formats: Monochrome

Figure 77 shows the normal operating conditions of hydraulic circuits 1A, 1B, 2A, and 2B. A little accumulator bottle, valve and, pressure needle are symbolic of the hydraulic system. In Figure 78 circuits 1A and 2B have failed completely.

The cross-hatched border in Figure 79 indicates the subsequent emergency situation. The failed systems are shown in the upper corners with a solid cross through the system symbol. The circuits that have failed are indicated by the alphanumeric 1A and 2B. Of more importance to the pilot than which circuits have failed, or the schematic, is an indication of what he has lost in terms of aircraft capability. These are indicated in Figure 79 by the crosses and the open circles. In this case he has lost half control of the horizontal stabilizers, as indicated by the circles and the "1/2" superpositioned on those components. He has completely lost the right aileron and the right and left flap as indicated by the circle and crosses. The flaps are lost permanently as indicated by the solid cross. The right aileron loss is intermittent as indicated by the open cross. When the aileron control is restored the cross and circle will be removed. Other hydraulically operated components on the aircraft are indicated by the schematic and are not affected. These include the radar antenna, refueling probe, nosewheel steering, canopy, variable inlet ramps, control of the gun, aileron, rudder, main gear brakes, speedbrake actuation, and deployment of the tail hook. Not all aircraft would have all these features operated by the hydraulic system. Some of these would be electrically controlled.

Figure 80 shows an alternate emergency situation in which only hydraulic circuit 2A has failed. In this situation the aircraft has lost the main gear brakes, hydraulic operation of the refueling probe, and nosewheel steering.

Figure 81 displays the corrective actions that can be taken for the problems when hydraulic circuit 2A has failed. The landing gear can be extended, when airspeed is dropped below 200 knots, by pulling down on the landing gear handle, twisting it, and then pulling it out -- as indicated in the pictures. The refueling probe can be extended by using the emergency extender as indicated. When landing, braking can be accomplished with the emergency brake.

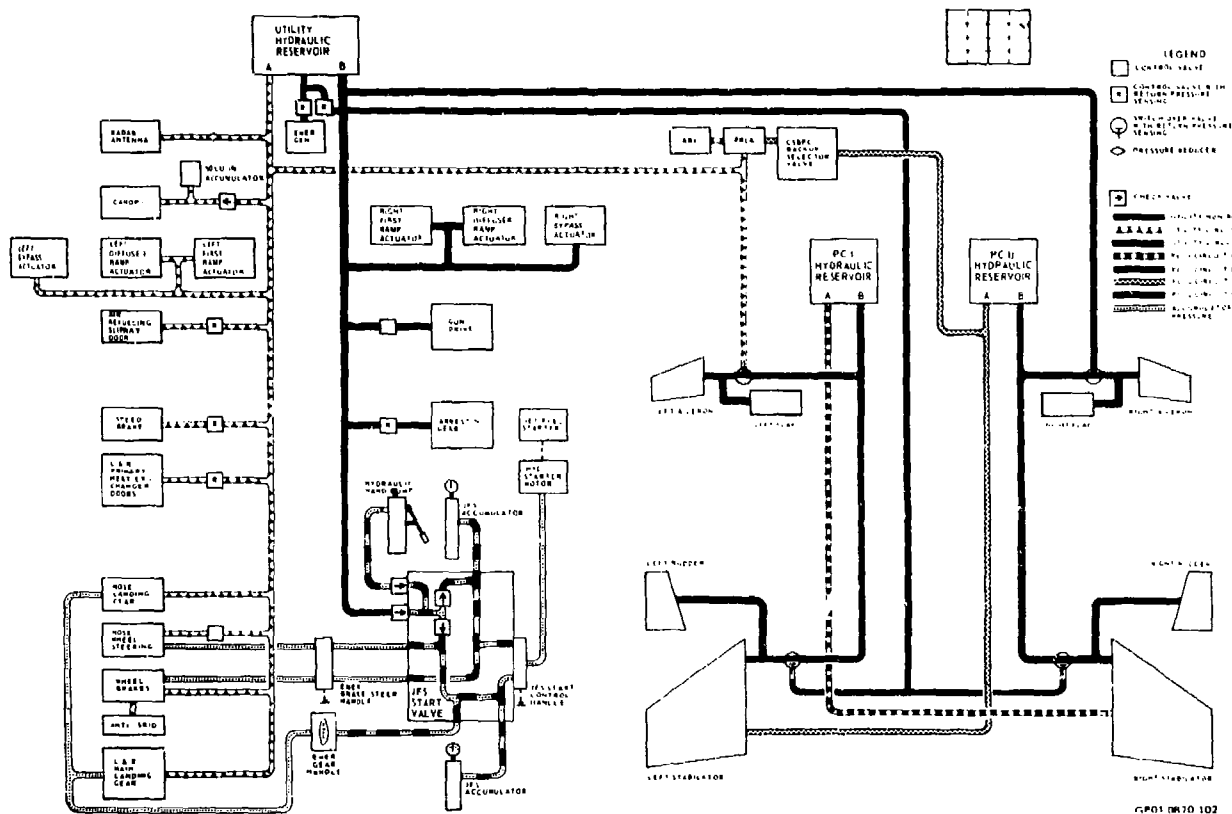


Figure 76
Typical Fighter/Attack Hydraulic System

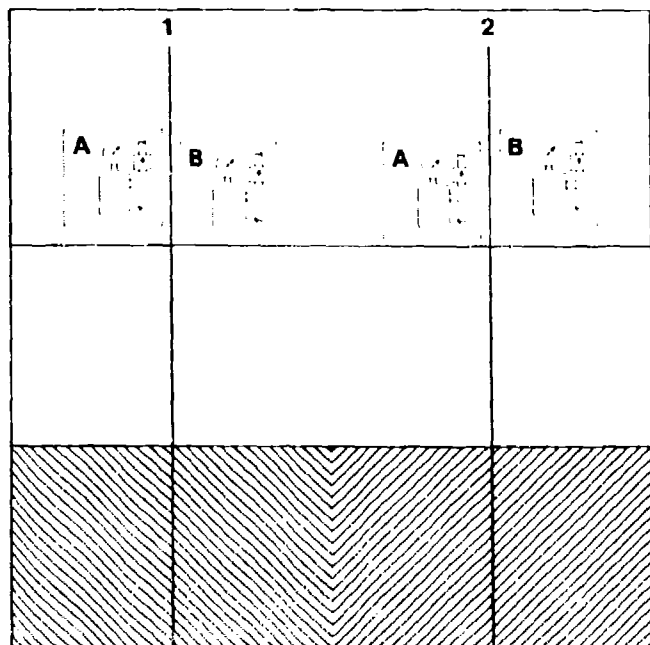


Figure 77
Normal Status Hydraulic System

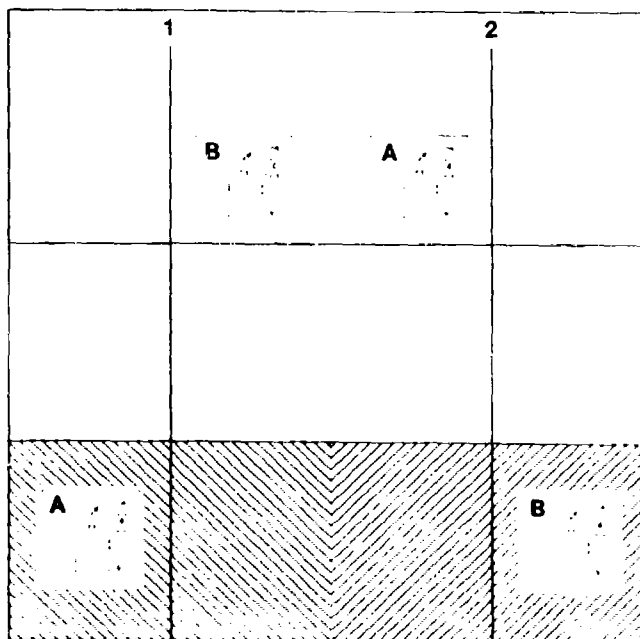


Figure 78
Degraded Status Hydraulic System

5.2.2 Hydraulic Formats: Color Stroke

In Figure 82 the cautionary emergency condition is indicated with yellow cross-hatched borders to imply that immediate action is not required. This is true when the hydraulic system circuit which is color-coded in violet has failed. The failed components -- nosewheel steering, refueling probe, and main landing gear -- are highlighted in yellow. The rest of the aircraft is outlined in mottled white consistent with self-designation.

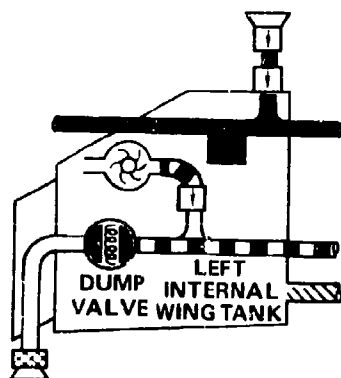
Figure 83 shows corrective action using color stroke symbology. The aircraft and unaffected control surfaces are indicated in white and the action to be taken is indicated in yellow which provides good contrast with the control circuits, the controls themselves and the black background. The control tower is magenta. The aircraft is white. And, the affected parts of the aircraft are yellow. Yellow is used to signify caution since action is not necessary until the pilot is actually landing the aircraft.

5.2.3 Hydraulic Formats: Color Raster

Figures 84 and 85 show the use of color fill to highlight the data available to the pilot. In Figure 84 aircraft components controlled and operated by the hydraulic system are shown in solid white. The rest of the aircraft is simply outlined in white to provide context to the primary hydraulic system information. Yellow fill is used to call attention to those systems which have failed as a result of circuit 2A failure.

Figure 85 illustrates the use of background fill to separate the general condition (black-filled) from the emergency actions which have brown-filled backgrounds. Varying background color serves as good contrast to accentuate the emergency action procedures to be followed by the pilot. The yellow cross-hatched border indicates an emergency caution situation.

5.3 FUEL SYSTEM



The fuel system schematic shown in Figure 86 is more complex than many fuel systems. Nevertheless, it illustrates the same type of excessive information that could be dumped on the pilot if careful consideration is not given to format development and integration. The pilot's interests are really in things like the distribution of the fuel, is it transferring properly, how much fuel is available, and what can be done to extend flying range with that fuel. For fuel available, most fuel gauges show pounds of fuel. A closer look at the problem reveals that the pilot is not really interested in pounds of fuel, since he must convert first to flight time available using fuel flow rate and then to range available.

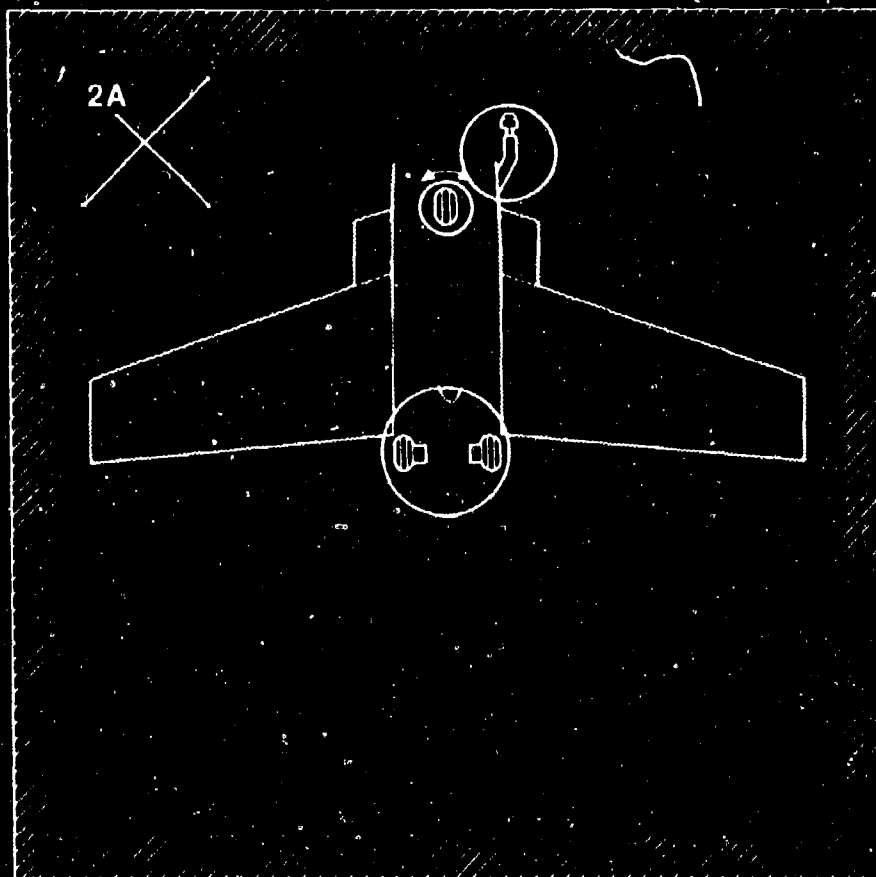


Figure 82
Degraded Hydraulic System Effects: Color Stroke

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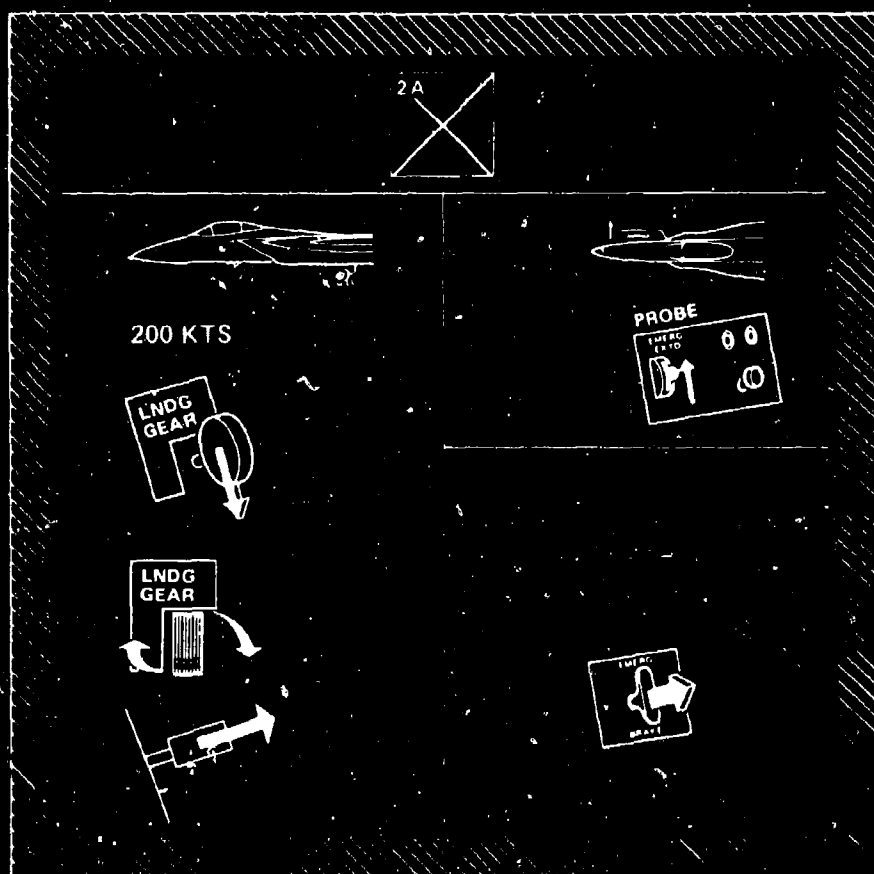


Figure 83
Hydraulic Emergency Actions: Color Stroke



Figure 85
Hydraulic Emergency Actions: Color Raster

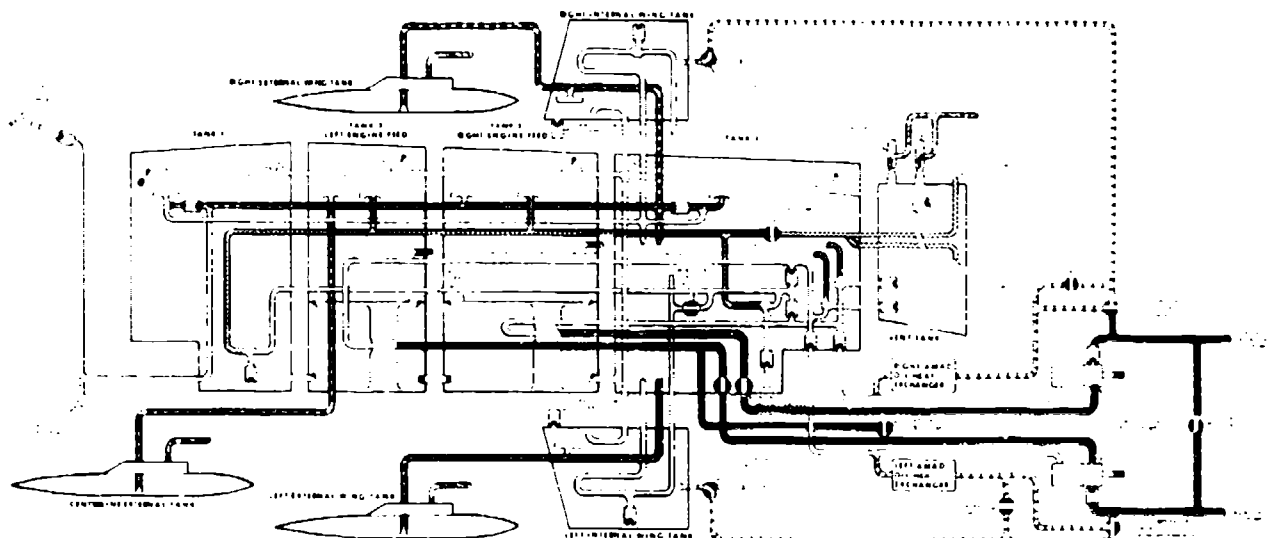


Figure 86
Fighter/Attack Aircraft Fuel System

The formats that follow take this situation into consideration. No specific emergency situations are shown explicitly in the fuel display since the most serious emergency specific to fuel is when fuel is gone or about to be depleted. Even that seriousness is dependent upon the proximity to appropriate landing facilities. Therefore it is difficult to judge in processing information what is and is not an emergency. The typical approach to the problem is to use a Bingo fuel indicator to alert the pilot that a predetermined level has been reached and it is time to break off and go home. Continuous calculation and updating of Bingo fuel could be assumed and used as a basis for presenting an emergency display with cross-hatched borders. It is felt, however, that the formats presented give the pilot sufficient information to let him make his own decisions in a most efficient manner.

5.3.1 Fuel Formats: Monochrome

Figure 87 answers the pilots concern about fuel distribution, showing the main tanks, the wing tanks, and external tanks. It also shows the status of key fuel flow valves and boost pumps. The pilot can readily discern from this display if the fuel is properly distributed and if it is properly transferring from one tank to another.

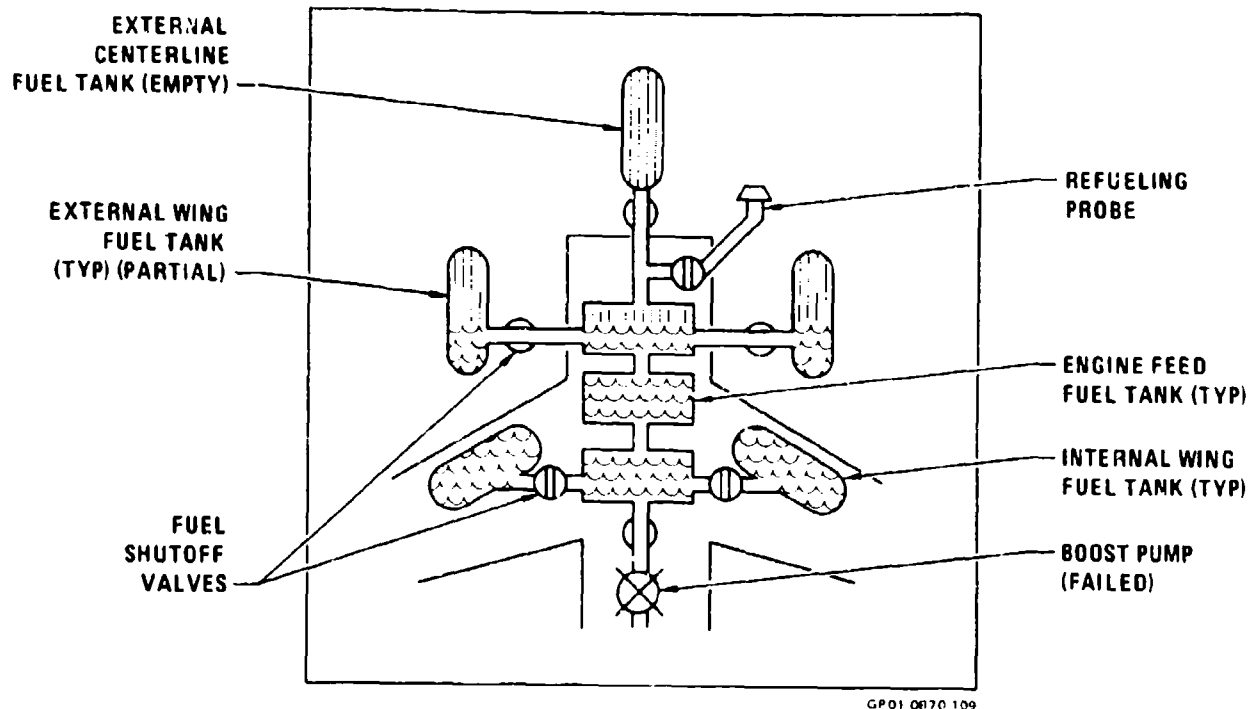
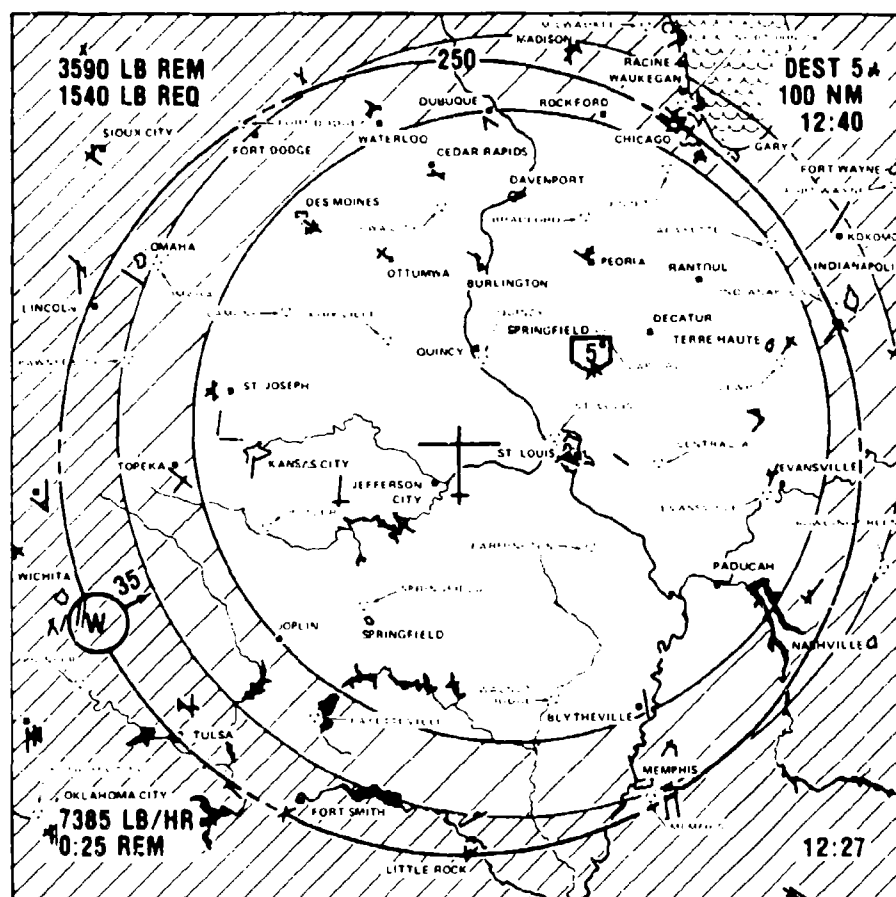


Figure 87
Fuel Distribution

Probably of even more concern to the pilot is the range available with the given fuel as shown in Figure 88. In this example the current time is 1227, estimated arrival time at destination number 5 (100 nautical miles away) is 1240. The aircraft is using 7385 pounds of fuel per hour and at this rate has 25 minutes of flight remaining. It also shows that 3690 pounds of fuel remain and 1545 pounds are required to reach destination number 5. While alphanumeric give exact quantitative data, the pilot can readily perceive the situation by looking at the map in figure 88. The innermost endurance range ring shows the range that can be reached from the current position by continuing to fly as is. The outer endurance range ring shows the maximum range attainable through an optimal combination of airspeed, altitude and fuel flow. The fuel endurance rings are biased about the aircraft symbol to account for wind velocity effects. The constant range ring, 250 NM in this example, scales the display. The wind direction is indicated by the arrow pointing from the circled "W" symbol on the constant range ring. Windspeed is numerically given as 35 knots in this example.

This type of display with a map background gives the pilot an immediate evaluation of where he is with respect to various goals in his flight plan or to alternate bases or airports.

If he determines that his goals are marginably achievable, he can use the fuel endurance display shown in Figure 99 in an attempt to reach maximum range. This display could be coordinated with a system such as the Integrated Flight Trajectory Control (IFTC) system. In this case the pilot would have the option of selecting automatic flight control by pushing a button peripheral to the display opposite the



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Figure 88
Fuel Limited Ranges

first option. The pilot could also elect to fly the same procedures manually by choosing the second button which would display command throttle settings and altitude to fly. It also reminds him that he has the option to jettison ordnance to further increase his range. The system would then adjust the endurance range rings in Figure 88 based on these changes to show current status in a dynamic update.

5.3.2 Fuel Formats: Color Stroke

Figure 90 shows a color stroke version of the aircraft fuel system in which the outline of the fuel system is brown and the aircraft outline is white to give context to the array of fuel tanks. Empty sections of the various tanks are outlined in yellow and the full sections are shown with blue "waves" rather than cross-hatching. This symbology change reinforces the color coding and vice-versa. As fuel is used the yellow and blue sections change proportionately. The failed boost pump near the tail section is shown with a red X through it.

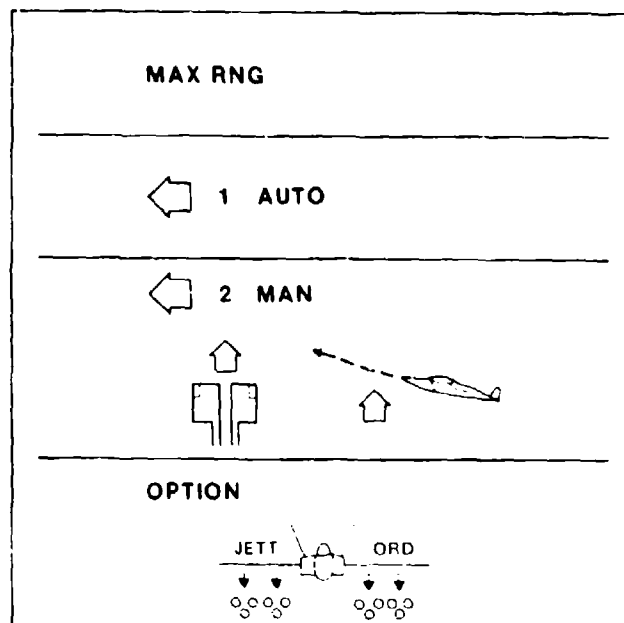
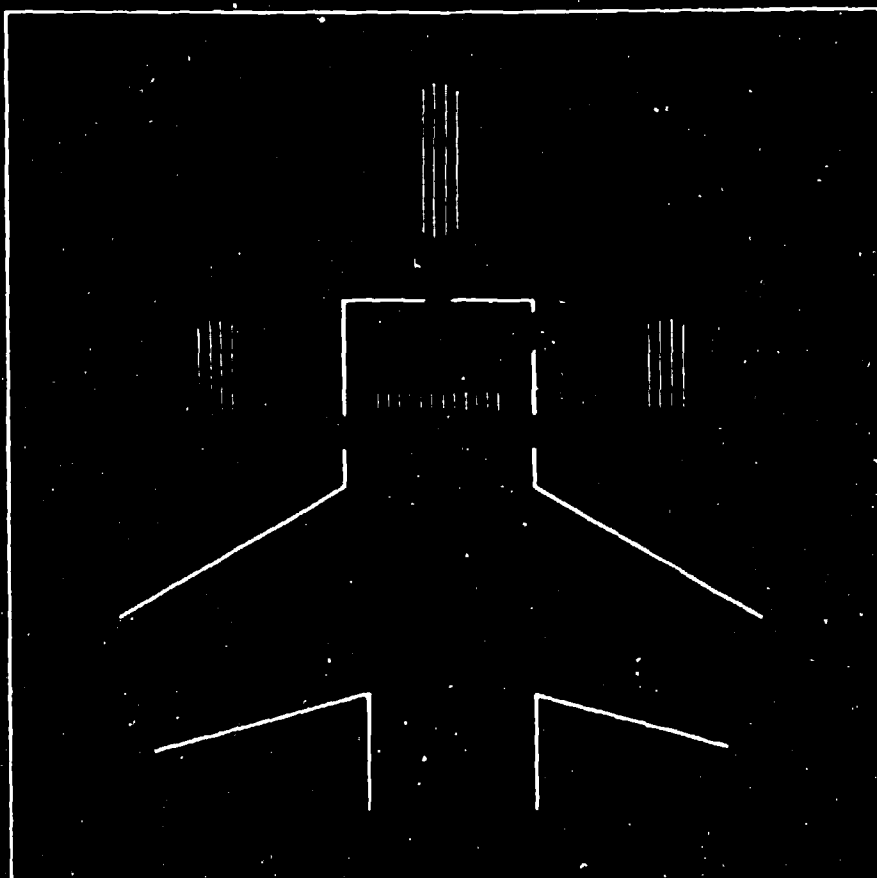


Figure 89
Fuel Endurance Procedures

Figure 91 indicates the color stroke version of the map. The inner endurance range circle is yellow showing precautionary range limits. The maximum range is noted in magenta. Magenta was chosen over red because red is reserved for emergencies requiring immediate action. The maximum endurance range does not necessarily signify an emergency. It is simply predicting future conditions. It is the pilot's discretion to place those conditions in a broader context and determine if any emergency exists. Alphanumerics are coded in orange and white. Those in white give fuel remaining (upper left display), fuel flow and time remaining (lower left display). Those in orange indicate other available information such as present time (lower right display) and information pertaining to a selectable destination (upper right display). The color coding on the map is consistent with that used in the tactical situation display. The map is essentially the same as the situation display and is really a navigation map indicating navigation aids, airports, and cities in relation to the centered white aircraft symbol.

The color stroke version of the fuel endurance procedures (Figure 92) uses color coding consistent with other displays. As with all displays the symbology is dynamic. As the throttles are moved forward to their appropriate positions, the arrow indicating commanded throttle position would decline until the appropriate position was reached and then would disappear. Likewise the climb command would recede as the appropriate altitude is reached. If ordnance is jettisoned, it would no longer appear on the screen as an option.



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Figure 90
Fuel Distribution: Color Stroke

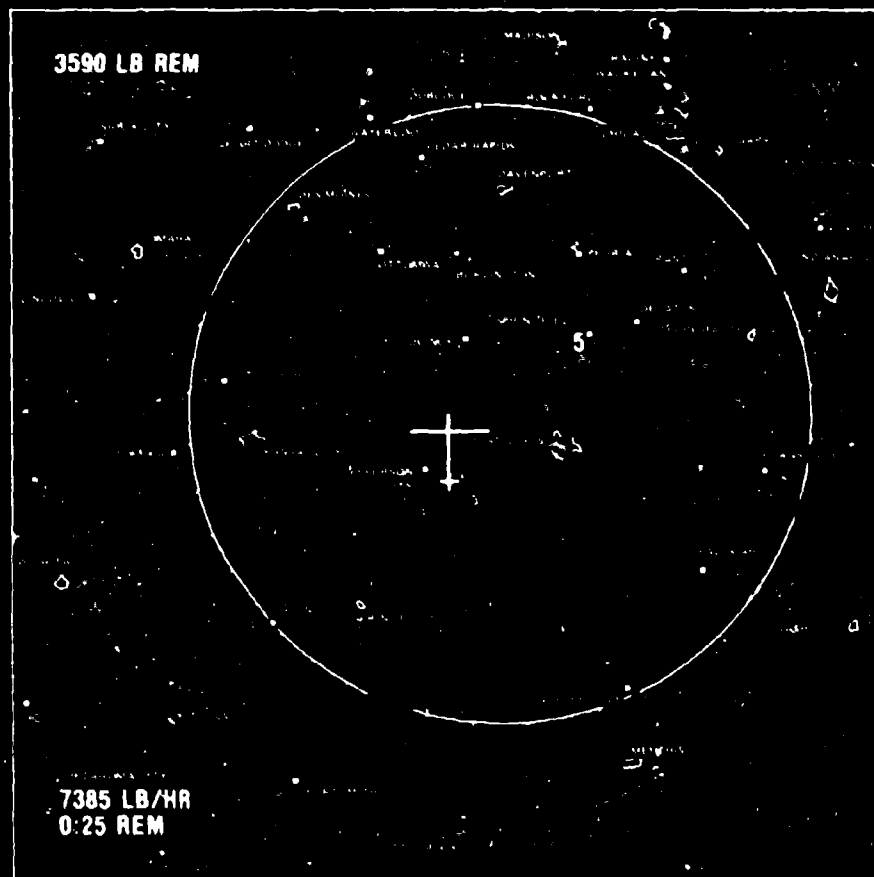
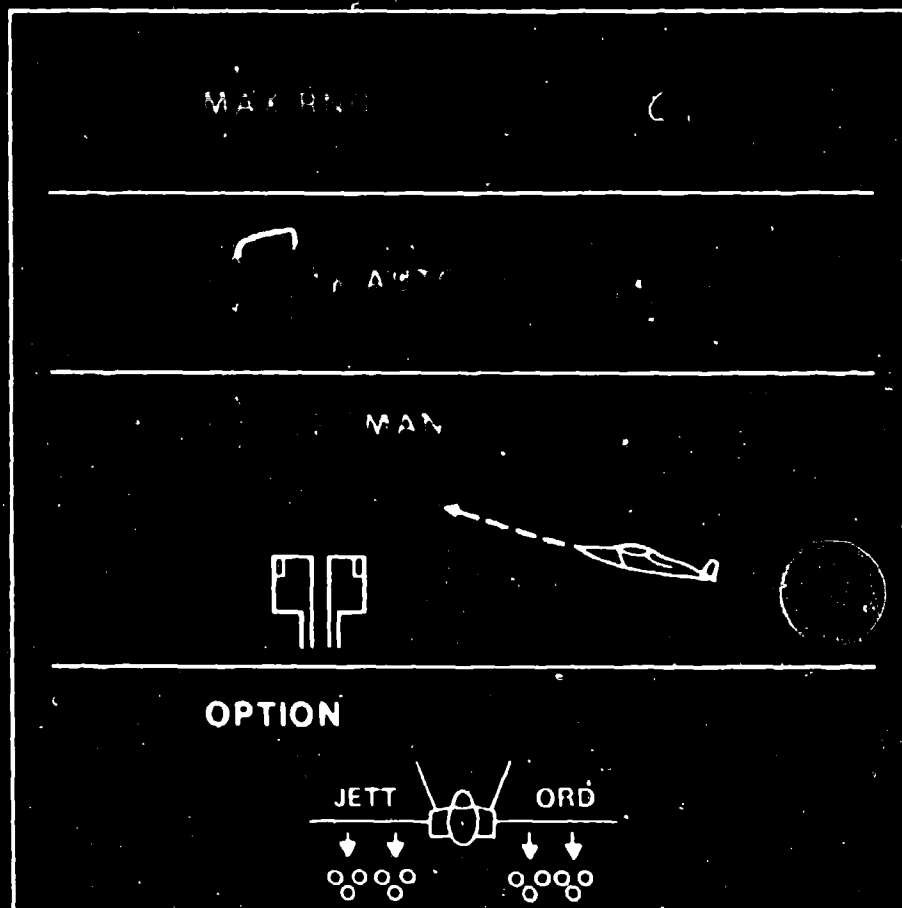


Figure 91
Fuel Limited Ranges Color Stroke



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Figure 92
Fuel Endurance Procedures: Color Stroke

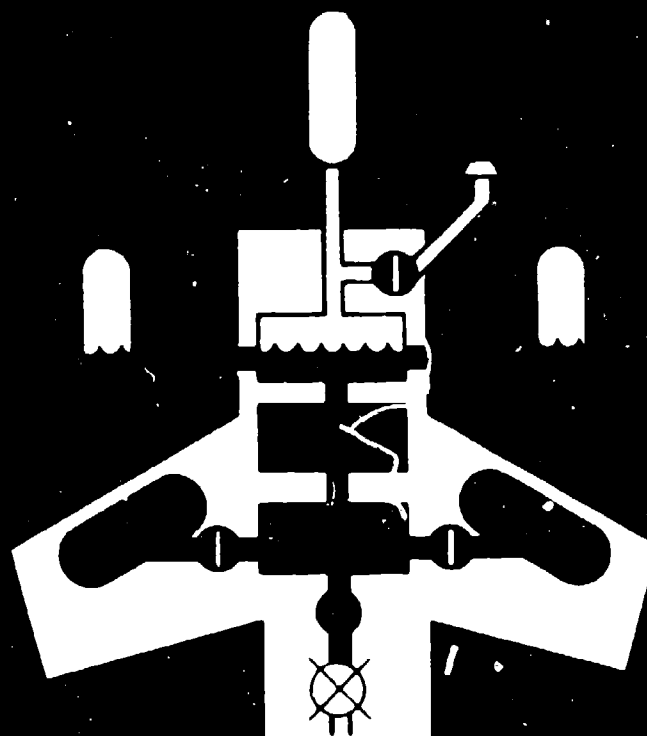


Figure 93
Fuel Distribution: Color Raster

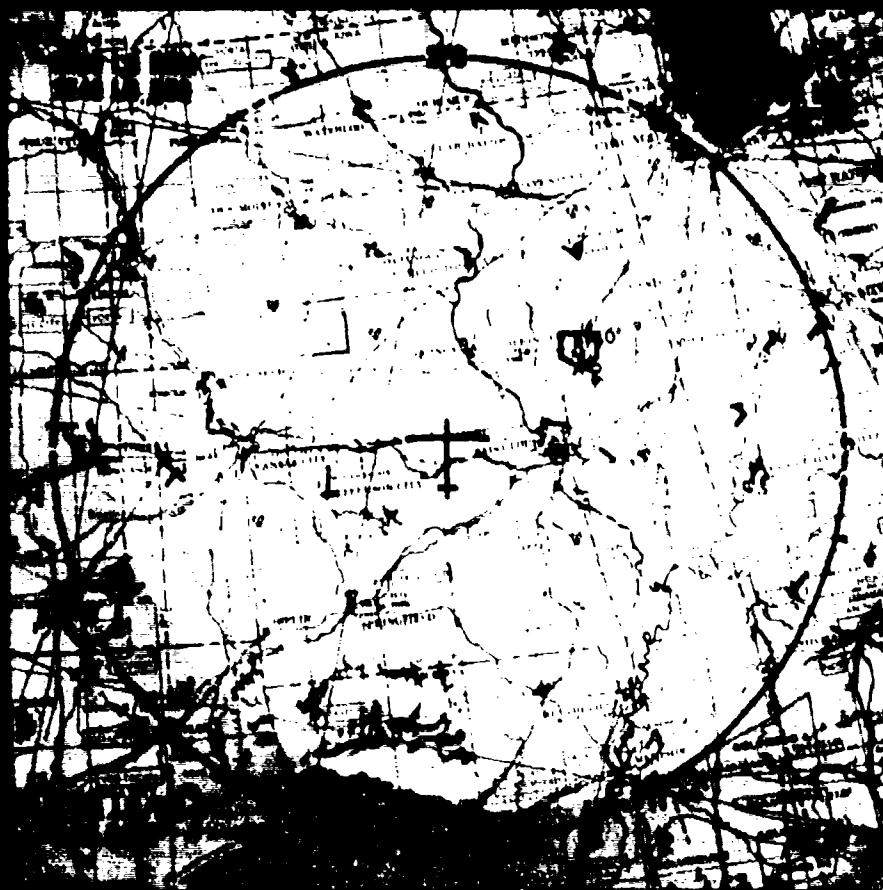


Figure 94
Fuel Limited Ranges: Color Raster

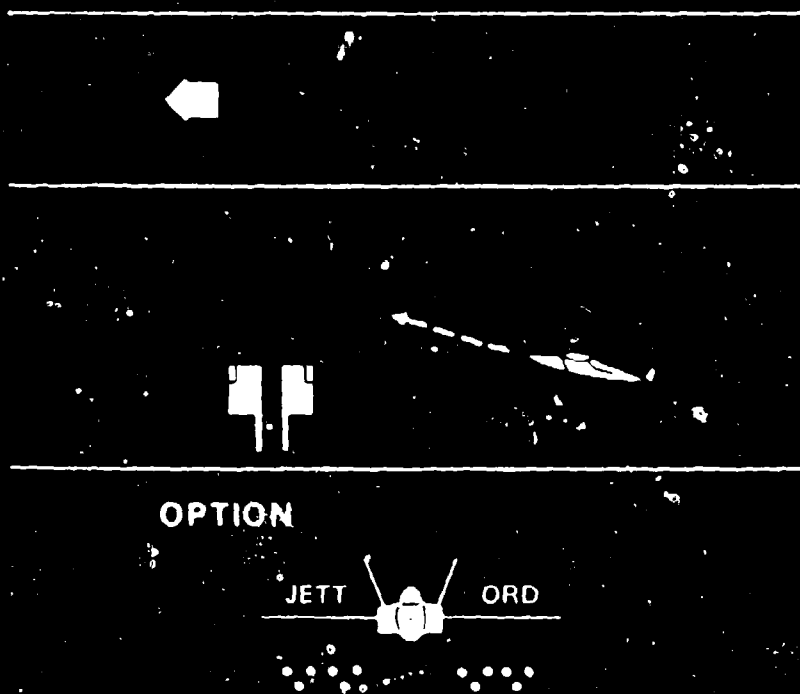


Figure 95
Fuel Endurance Procedures: Color Raster

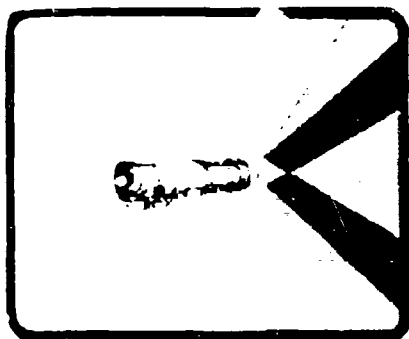
5.3.3 Fuel Formats: Color Raster

Figure 93 is the color raster format for fuel distribution. It uses yellow fill for empty tanks and blue with waves to show fuel level. The aircraft is outlined in white. As the valves are opened or closed they will change on the display indicating the appropriate open, closed, or failed condition. The refueling probe is shown in an extended or retracted position depending upon current state. The fuel level in each tank changes as the tank fills, empties, or fuel is transferred from one tank to another.

Figure 93 again shows the use of background color fill to differentiate steps to be taken.

Figure 94 shows the full color fuel range display. Symbolology remains the same as in previous versions of this format except that the precautionary range limit is shown now as a yellow band rather than a ring and the maximum possible range is now the inner edge of the magenta filled area (or the outer edge of the yellow band). As with the monochrome and color stroke displays, this display is fully dynamic: the endurance range bands grow or shrink according to fuel usage and remaining fuel on board, and the map translates under the aircraft as it does in the tactical situation display (TSD).

5.4 ENGINES



A two engine aircraft is assumed. It is interesting to note that the only primary control the pilot has over the engines are the throttles. Other functions such as inlet ramp and exhaust nozzle adjustments are controlled automatically by preprogrammed processors. Secondary controls are limited to fuel shut-off, in conjunction with deploying the fire extinguishers, and engine start procedures. Nevertheless, pilots insist on knowing things such as the turbine inlet temperature (TIT), the N1 (FAN) and N2 (COMPRESSOR) speeds, the exhaust gas temperature (EGT), and perhaps

even inlet positions and engine exhaust nozzle positions.

Figure 95 shows the full color raster version of the fuel endurance procedures display. The symbolology and color coding are identical to that of the color vector graphic display (Figure 92) with one exception: the arrows on Figure 95 showing jettison of ordnance have been color-coded green.

5.4.1 Engine Formats: Monochrome

Figure 96 shows the nominal engine display with the TIT, N1, fuel flow, N2 and EGT parameters all operating nominally. The inlet ramps and exhaust nozzle ramps are shown in nominal positions, with the maximum open and closed positions shown as dashed lines. The exhaust in the burn chamber indicates the engines have ignited. Fuel flow and flow rate are shown by the relative size of the arrow pointed toward the engine (contrast Figures 96 and 97 for example) and by the movement of the bubbles toward the engines. The rate of this movement is proportionate to actual fuel flow rate. The basic format for the parameters is a ribbon-type display.

In Figure 97 there is a disparity in fuel flow to the engines. The engine speed and temperatures on the left engine have approached the maximum normal operating conditions. Also, the extra plume on the left engine indicates that it is in afterburner. This situation is abnormal and has been created to illustrate parameter excursions and different format features.

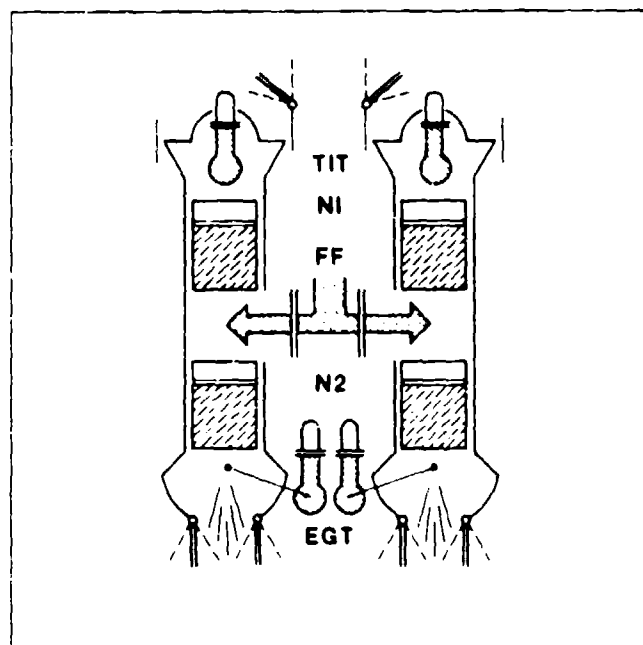


Figure 96
Nominal Engine Display

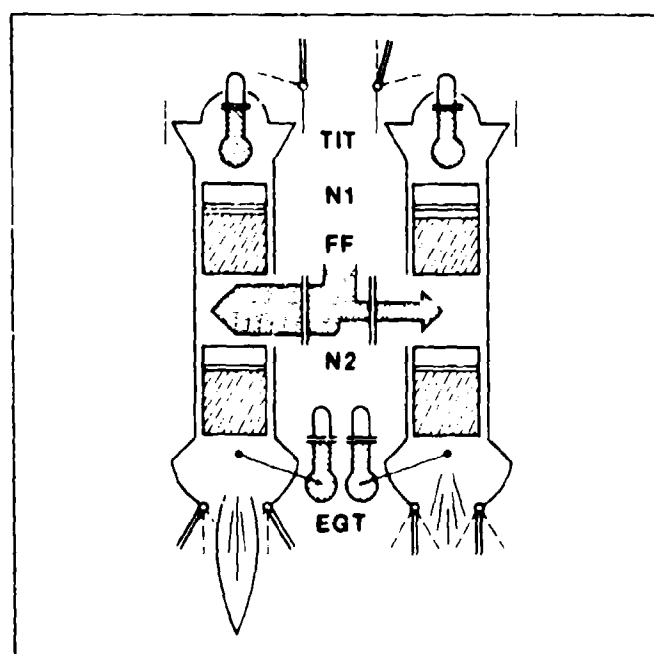


Figure 97
Abnormal Engine Status

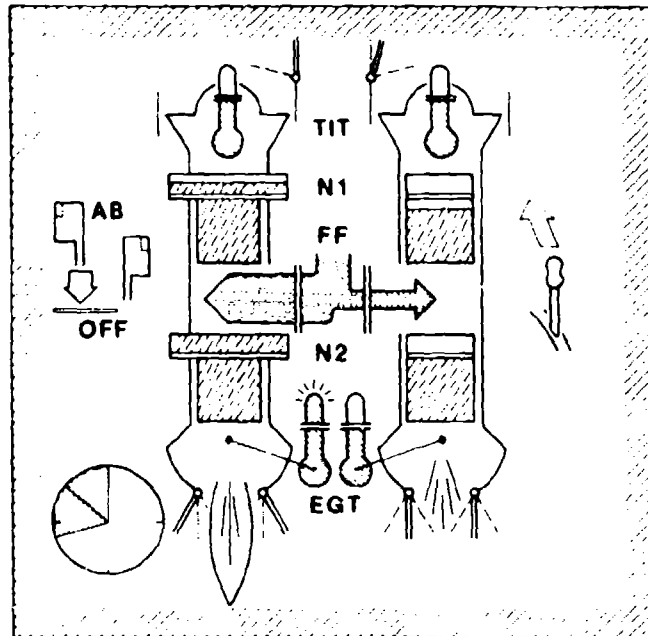


Figure 98
Emergency Engine Status and Corrective Action

Figure 98 shows a continuation of the abnormal engine operation in which the engine speeds and the exhaust gas temperature for the left engine have exceeded normal. An emergency condition is declared on the display by a cross-hatched border. Commands have been posted to reduce the left engine throttle setting to a much lower position. Only extreme throttle positions AB (afterburner) and OFF are shown. Two other positions, M (military power) and I (idle), were deleted from earlier concepts. Discussions with pilots indicated that since M and I were simply the positions immediately before AB and OFF, that a command to position at M or I could be easily shown by an arrow pointing to the side of a line opposite that of OFF (or AB). Such a case for IDLE is shown in Figure 98, with the OFF command shown in Figure 100.

In some instances it may be necessary to change the aircraft attitude to get more airflow through the engines in order to accommodate the large fuel flow. This is indicated by the stick command. Such a command of course would have to be a very "smart command" because it would certainly be foolish to command such a movement when the aircraft is at low altitudes or in an awkward attitude. The clock in the lower left corner indicates the allowable time the engine can continue to operate in this overspeed and overheated condition. Two types of cross-hatching might be used for two sets of conditions. For example the engine might be allowed to operate at 105% for 10 minutes and an additional 10 minutes at 103% of speed, or whatever the parameter of concern is. While in many cases this clock is not necessary, it is included here to show the type of features that could be included in the display.

In Figure 99 the engine overspeed/overheat condition has continued until a fire has broken out in the left engine. This is certainly an emergency situation and is indicated by the cross-hatched border surrounding the display (caution formats would have a less dense cross-hatching for the monochrome displays). The throttle is being commanded down to the idle position.

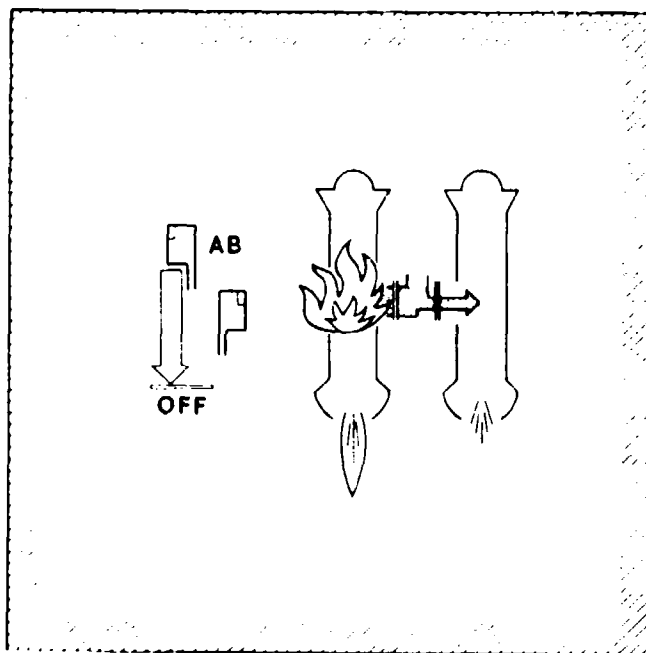


Figure 99
Engine Fire and Emergency Procedure

In the left format of Figure 100 the throttle has been moved to the idle position but the fire persists. The throttle is being commanded to OFF. In the right format of Figure 100 the left engine throttle has been shut off but the fire still persists. The next step commanded is to use the fire extinguisher, which is indicated by the symbol in the upper left display. On a touch sensitive display surface pressing that part of the display activates the fire extinguisher. The right engine continues to operate normally.

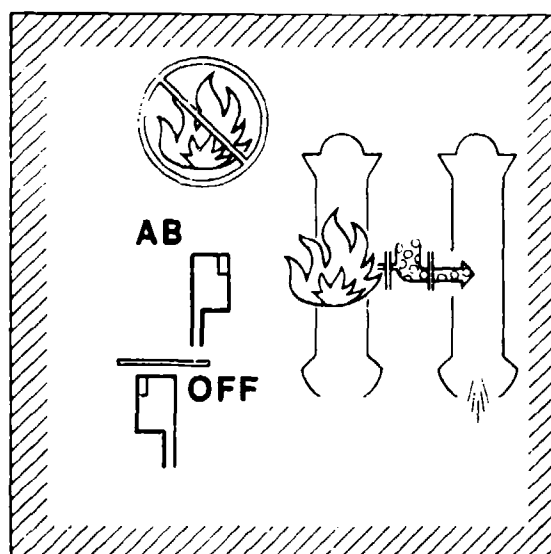
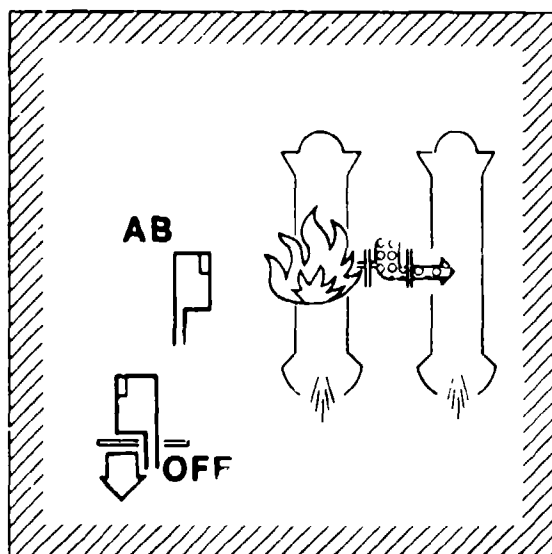


Figure 100
Engine Fire Emergency Procedures

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After using the fire extinguisher two options remain. If the fire is extinguished, the resulting display would become that shown in Figure 101. The left engine has failed, but the right engine continues to operate normally. The pilot can continue to use that engine, although he should proceed to land as soon as reasonably practical.

If the fire is not extinguished the display in Figure 102 results, indicating the fire extinguisher has failed and that a fire continues in the left engine. It shows that the only remaining practical action is to eject.

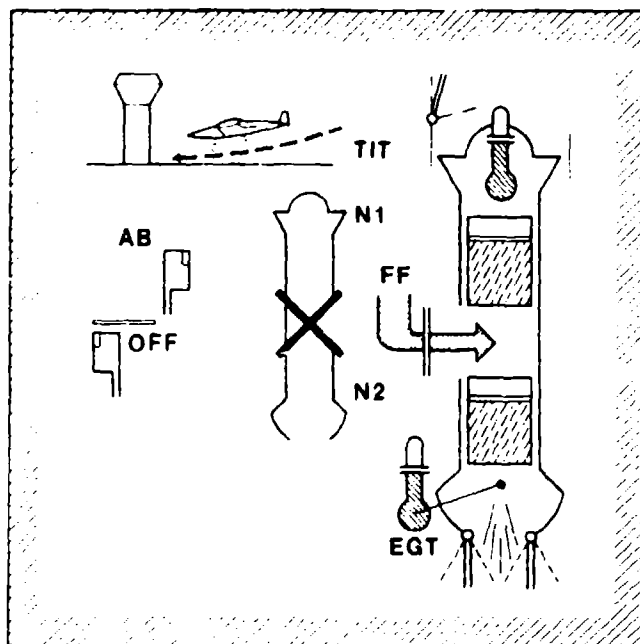


Figure 101
Emergency Action/Status with
Extinguished Engine Fire

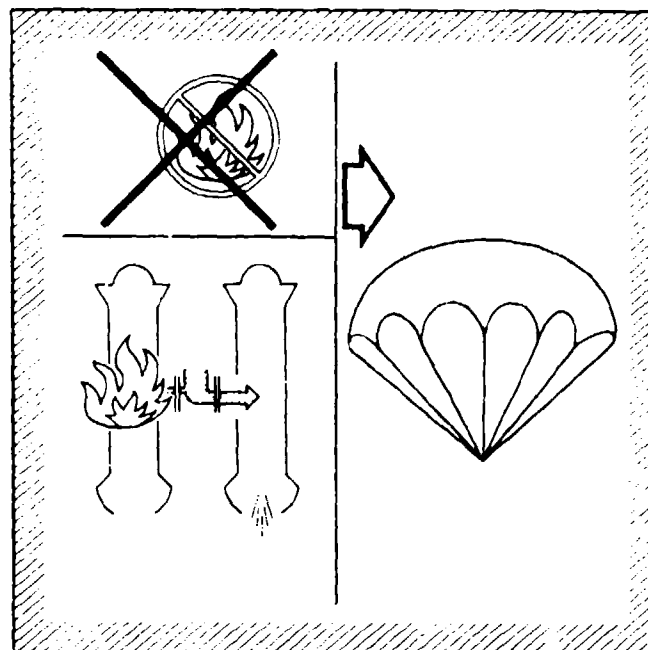


Figure 102
Final Engine Fire Emergency Action

5.4.2 Engine Formats: Color Stroke

In Figure 103, colors are used to reinforce the ribbon display characteristics for the various engine parameters. Acceptable temperatures and speeds are indicated by green in the ribbon. The white outlines are used for contrast. The yellow lines indicate the maximum normal operating conditions. Both engine speeds and temperatures are at maximum normal values for both engines. The fuel flow bubbles would effervesce through the fuel pipe and disappear into the combustion chamber of the engine. This is typical for fuel flow on all the engine displays.

Figure 104 shows the bottom two portions of each engine have reached the lower bounds of the caution speed range (single yellow line). The upper portions have exceeded these lower bounds of the caution range, but not yet reached the lower bounds of the emergency condition speed range. Thus, there are double yellow lines.

Figure 105 shows that the left engine speed parameters have gone into the yellow for N1 and to the red condition in N2. Likewise the EGT has exceeded safe operating limits and is in the red condition. At this point the situation is still precautionary as shown by the yellow cross-hatched border. The corrective stick and throttle commands are highlighted in yellow. The times available at 105% and 103% operating conditions are color coded in red and yellow on the clock.

In Figure 106 the emergency condition is indicated with a red crosshatched border. The troubled engine is outlined in red and the fire symbol is in the traditional red and yellow.

Figures 107, 108 and 109 function the same as described for the monochrome formats. The cold, inoperative engine in Figure 108 is blue and its failure is emphasized with the red solid X.

5.4.3 Engine Formats: Color Raster

The cross-hatched fill in the ribbon displays of TIT, N1, N2, and EGT is replaced by color raster fill. Orange fill is used to highlight the engine ignition symbol. Violet is used to fill the fuel flow path. Various color coordinated fills and backgrounds are used to emphasize status and corrective commands for the emergency situation formats. Green is used for parameters in normal operating ranges. Yellow signifies parameters that have exceeded normal values. Only cautionary operation can be continued in this condition. Red indicates excessively dangerous conditions that must be corrected immediately.

The color raster formats have the same features and dynamics as the monochrome and color stroke formats. The color raster formats are shown in Figures 110, 111, 112, 113, 114, 115 and 116.

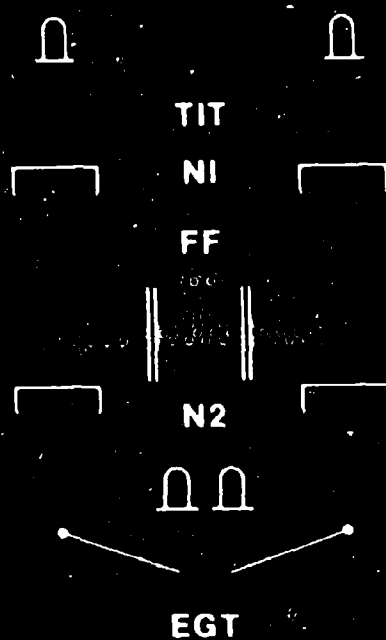
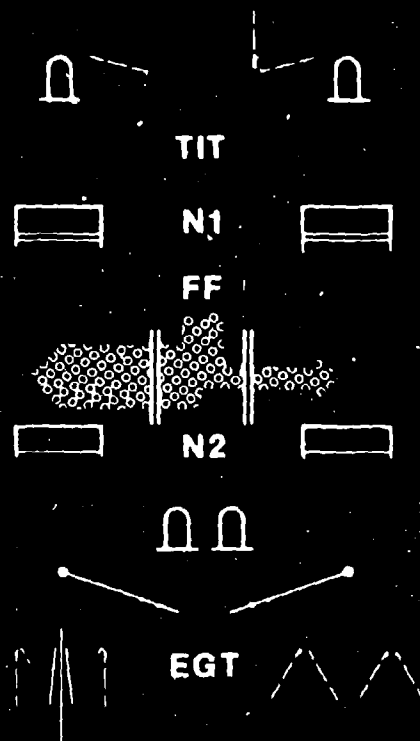


Figure 103
Nominal Engine Display: Color Stroke



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Figure 104
Abnormal Engine Status: Color Stroke

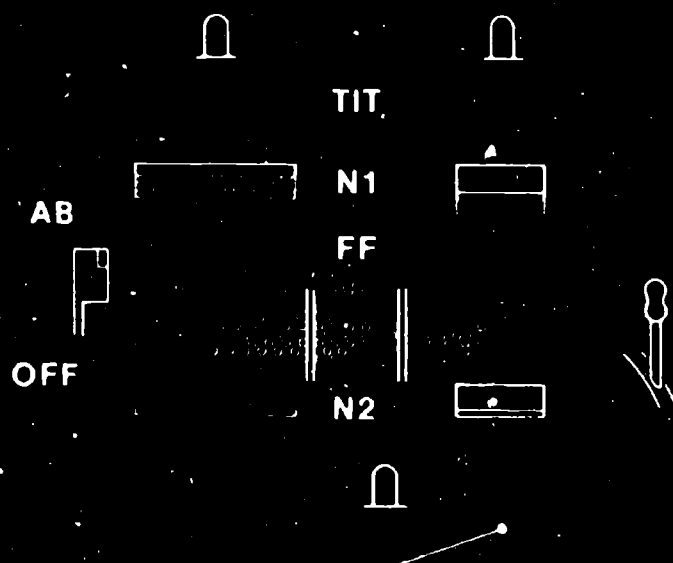


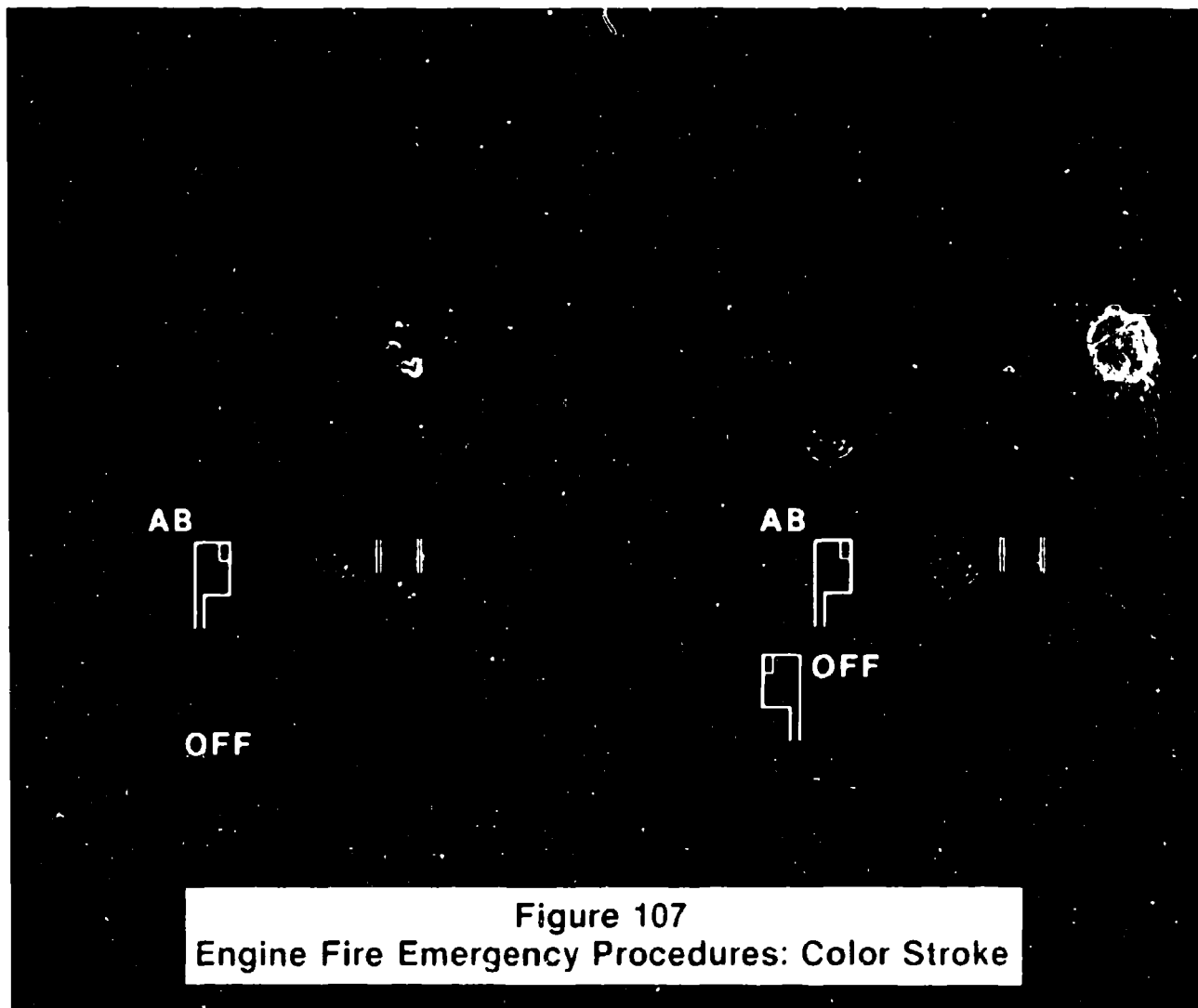
Figure 105
Emergency Engine Status and Corrective Action:
Color Stroke

AB



OFF

Figure 106
Engine Fire and Emergency Procedure: Color Stroke



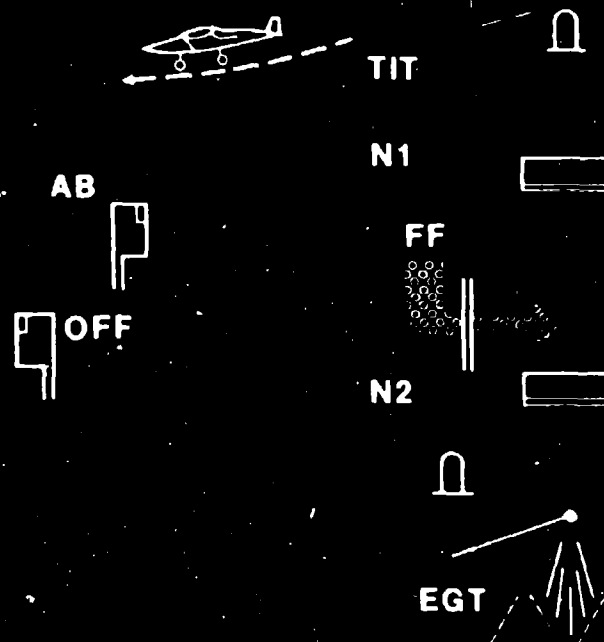


Figure 108
Emergency Action/Status with Extinguished Engine
Fire: Color Stroke

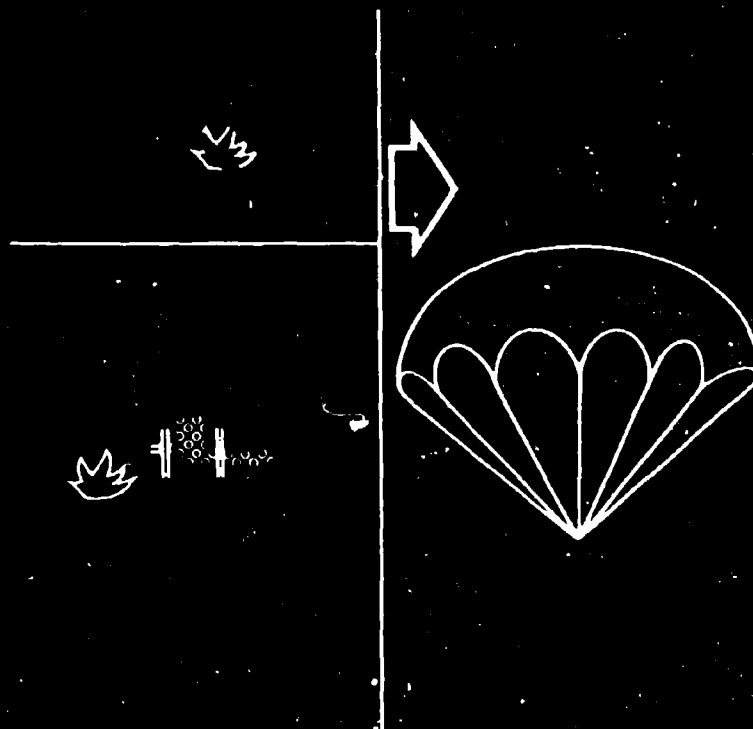
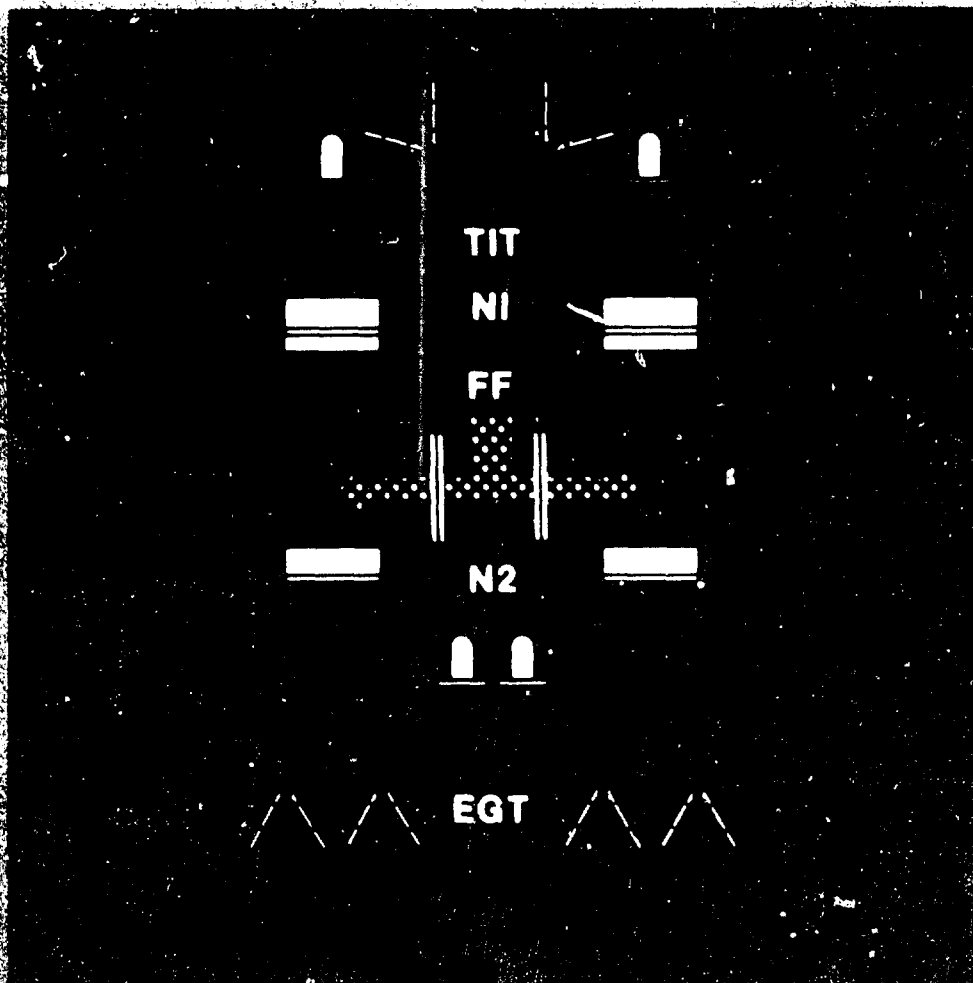


Figure 109
Final Engine Fire Emergency Action: Color Stroke

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GP01-0770-030

Figure 110
Nominal Engine Display: Color Raster

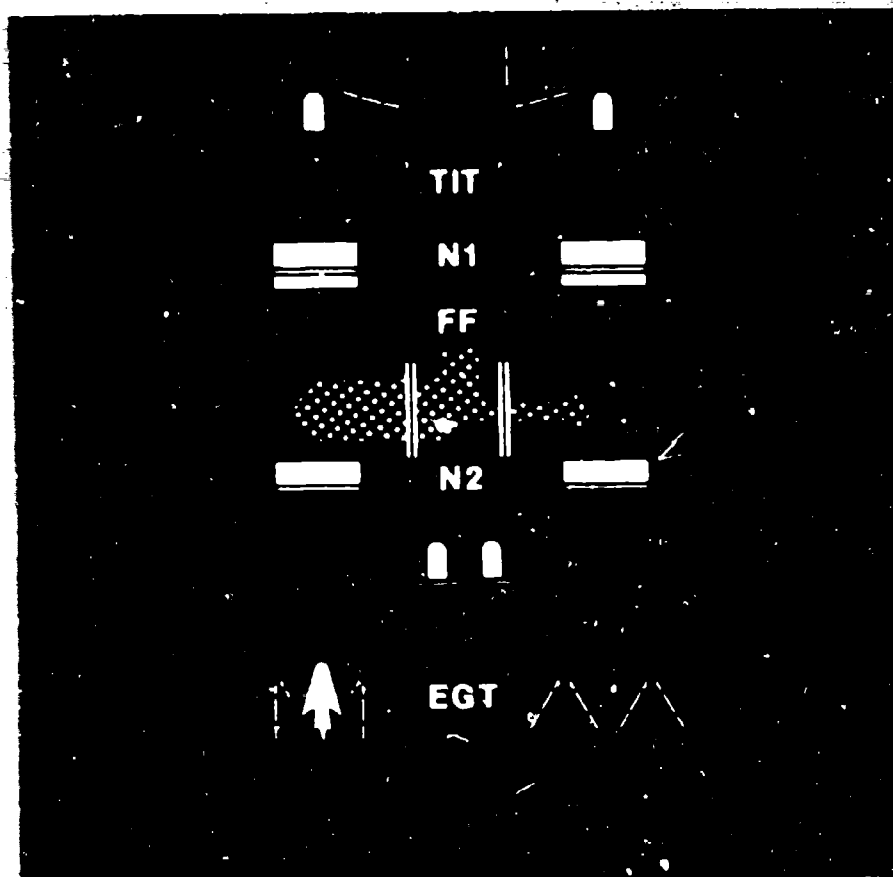
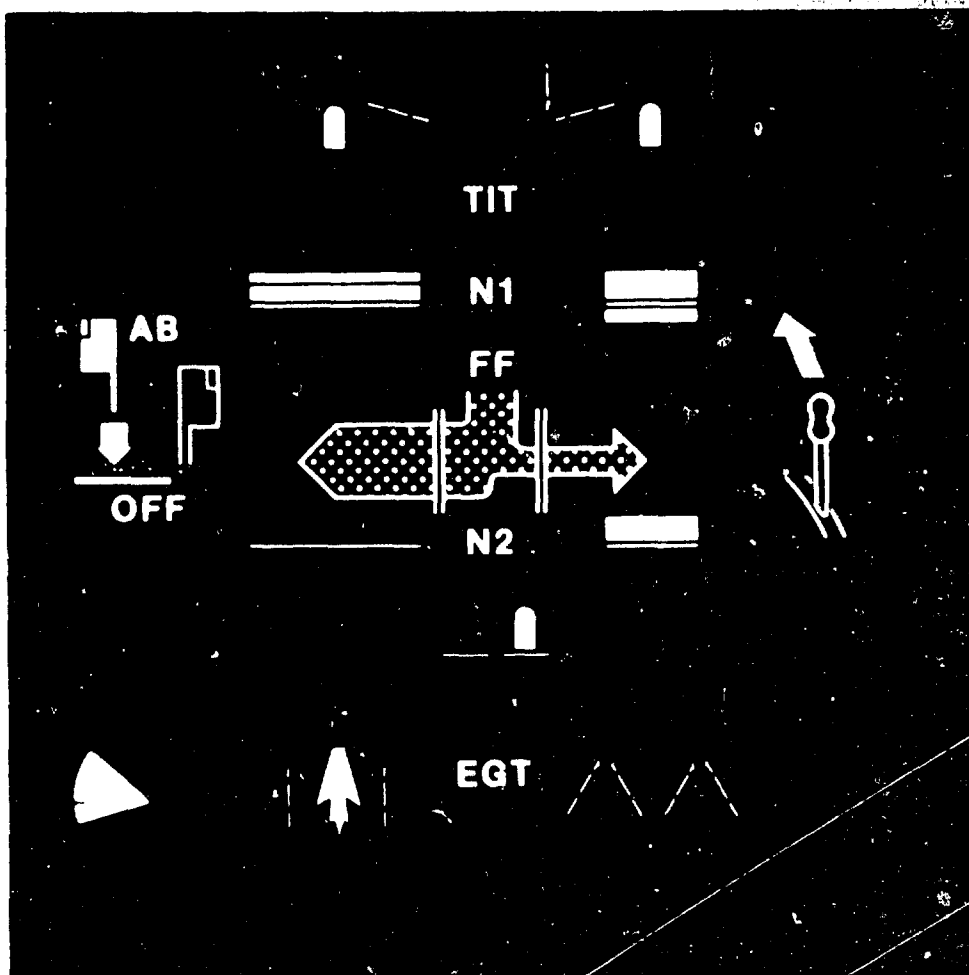


Figure 111
Abnormal Engine Status: Color Raster



GP01-0870-309

Figure 112
Emergency Engine Status and Corrective Action:
Color Raster

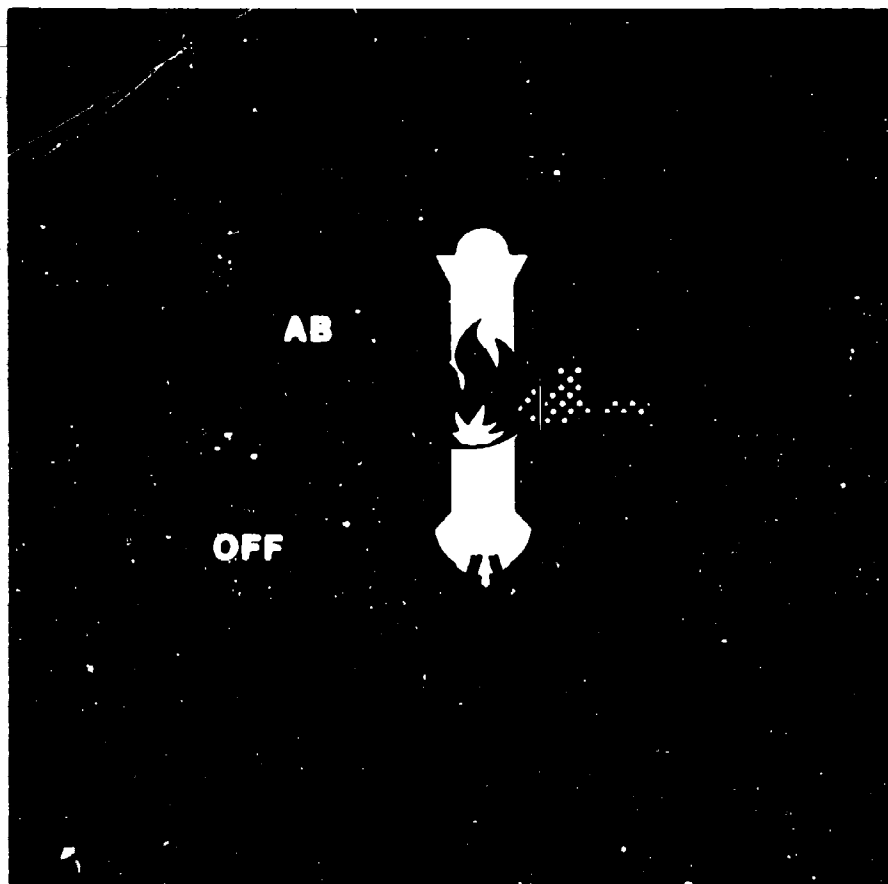


Figure 113
Engine Fire and Emergency Procedure: Color Raster

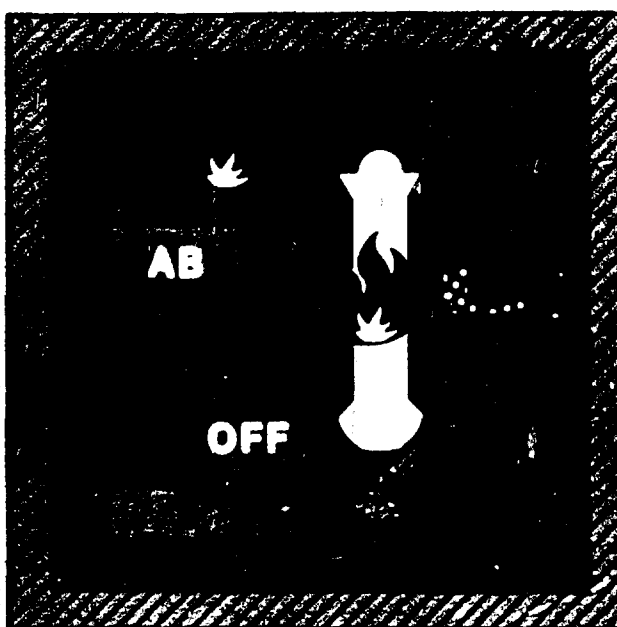
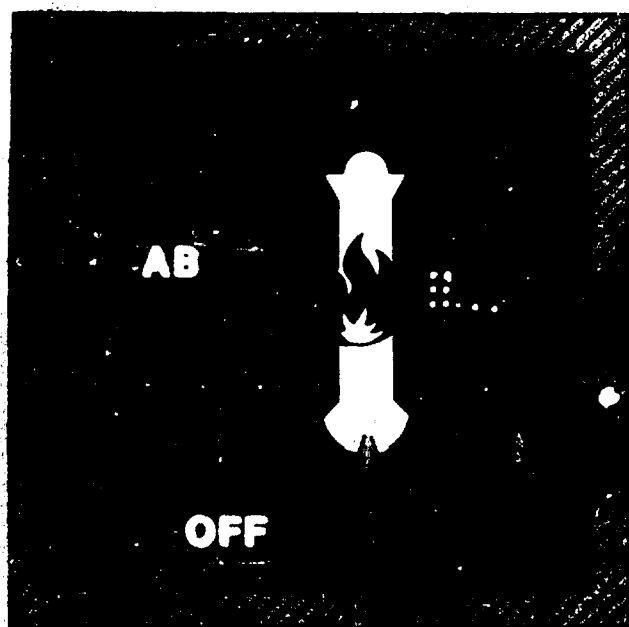


Figure 114
Engine Fire Emergency Procedures: Color Raster

GP01-0070-071

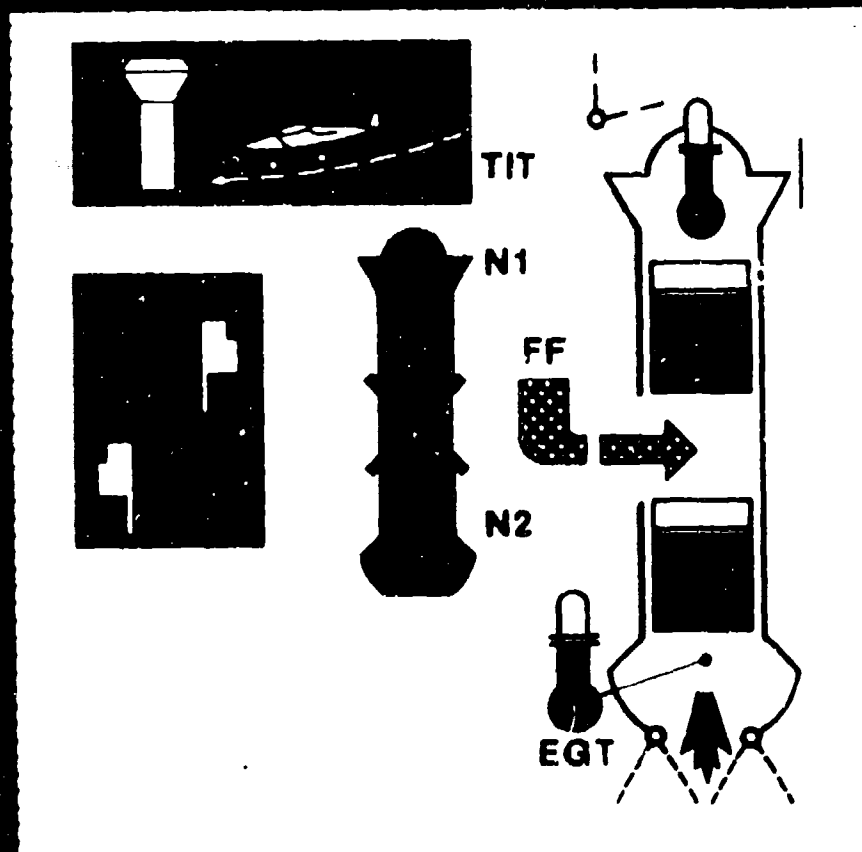


Figure 115
Emergency Action/Status with Extinguished Engine
Fire: Color Raster

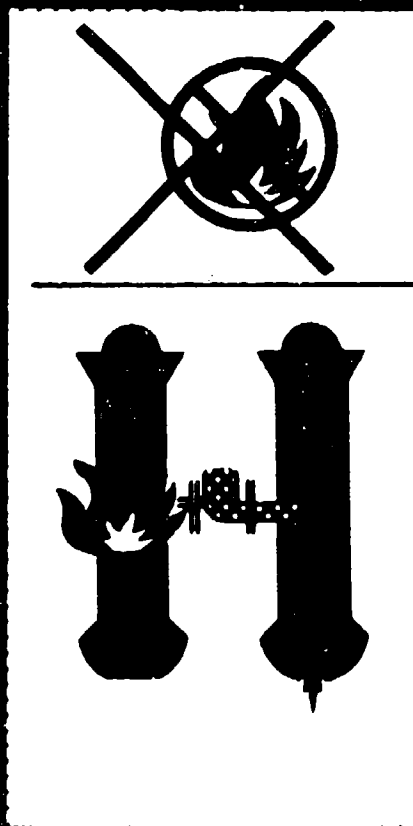


Figure 116
Final Engine Fire Emergency Action: Color Raster

6. CONCLUSIONS AND RECOMMENDATIONS

The resulting formats open new horizons of information display in fighter/attack aircraft. They expand the applications of multi-mode displays which are themselves a giant step forward in the concept of cockpit design.

As expected with research and development efforts, the individual results range from successful to not successful. Some of the formats have rather obvious interpretability advantages over the alphanumeric (A/N) displays. Examples are the engine fire (Figure 99, etc), and the ejection parachute (Figures 102, 109 and 116). Others, such as the electrical fuzing options in Figures 49, 53 and 57, have a subtle advantage. The A/N versions of these in left to right order are VT (variable or proximity), INST (instantaneous), DLY 1 (delay 1), and DLY 2 (delay 2). The pictorial formats show what happens with each fuzing choice, even to an untrained observer, while the A/N formats require training to learn the meaning of the VT and DLY abbreviations and how the fuzing alters the weapon effect on the target.

The format with fuel limited ranges on a map background (Figures 88, 91 and 94) has very significant interpretability advantage and should require only very modest training.

Some formats have advantages that are not immediately evident and require modest training, but they can transfer data that is otherwise incomprehensible in an A/N format. Two examples of this are the TSD formats in Figures 40 and 42.

"Questionable value" best describes other format features. An example is identification of air-to-surface delivery programs in the stores management displays. Current practice is to assign a number to each delivery program. The pictorial format graphically portrays the target against which the program is to be used. Examples are the bridge in Figures 48, 52 and 56 and the tank in Figures 49, 50, 53, 54, 57 and 58. Another example of a "questionable value" feature is the hand releasing a bomb in the stores management formats.

The unsuccessful formats have had pictorial formats contrived to replace the A/N's. The master arm indication (Figures 47, 51 and 55) is an example. Compare this to the A/N version in Figures 48, 52 and 56. The automatic release mode (left most symbol in the MODE row of Figure 49) is another example.

A/N's were used only when absolutely necessary. A mix of A/N's and pictorials would undoubtedly improve the next format development iteration.

Display dynamics were considered but there is much room for improvement and development with this parameter of the formats. However, excessive use of dynamic features can annoy rather than help the pilot.

Pictorial attack displays (air-to-air and air-to-surface weapon delivery, target designation, etc.) need to be investigated and developed.

All formats must be carefully integrated into an aircraft weapon system design. The display formats and their dynamic interaction depend on how system components work and the logic in a mission computer or other controller. In the iterative design process, pilot reaction to a format is fed back to alter the integration logic. The formats are often changed in an iteration cycle, therefore realistic format development should always be done within the context of a baseline aircraft weapon system.

Further studies are needed to simulate and evaluate these formats. Attack displays should be developed. A set of formats should be developed for a specific baseline aircraft (e.g., F-15E) to look at the operational application and more exactly determine the image processing requirements.